EXHIBIT F

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(12) **United States Patent**
Shabtay et al.

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(45) **Date of Patent: May 14, 2019**

(54) **MINIATURE TELEPHOTO LENS MODULE AND A CAMERA UTILIZING SUCH A LENS MODULE**

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(73) Assignee: **Corephotonics Ltd**, Tel Aviv (IL)

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§ 371 (c)(1),
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(51) **Int. Cl.**

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G02B 9/60	(2006.01)
H04N 5/225	(2006.01)
G02B 7/02	(2006.01)
G02B 13/06	(2006.01)

(Continued)

(52) **U.S. Cl.**

CPC ***G02B 13/001*** (2013.01); ***G02B 7/021*** (2013.01); ***G02B 9/60*** (2013.01); ***G02B 13/0045*** (2013.01); ***G02B 13/02*** (2013.01); ***G02B 13/06*** (2013.01); ***G03B 17/00*** (2013.01); ***H04N 5/2253*** (2013.01);

(Continued)

(58) **Field of Classification Search**

CPC .. G02B 13/001; G02B 13/0015; G02B 13/02; G02B 13/0025; G02B 13/003; G02B 13/0035; G02B 13/004; G02B 13/0045; G02B 13/04; G02B 9/06; G02B 9/12;

(Continued)

(56) **References Cited**

U.S. PATENT DOCUMENTS

2,354,503	A	7/1944	Cox
2,378,170	A	6/1945	Aklin

(Continued)

FOREIGN PATENT DOCUMENTS

CN	102739949	A	10/2012
CN	103024272	A	4/2013

(Continued)

OTHER PUBLICATIONS

A compact and cost effective design for cell phone zoom lens, Chang et al., Sep. 2007, 8 pages.

(Continued)

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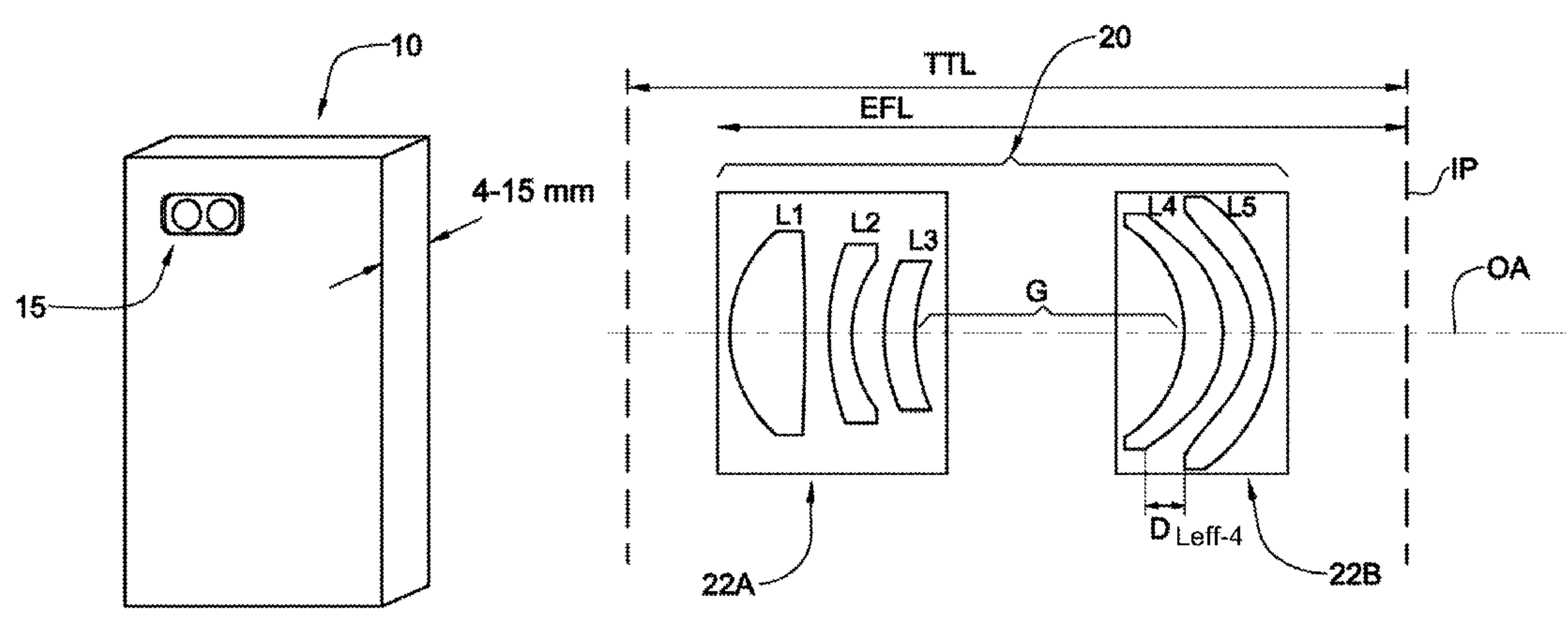
(57) **ABSTRACT**

The presently disclosed subject matter includes a mobile electronic comprising an integrated camera, comprising a Wide camera unit comprising a Wide lens unit, and a Telephoto camera unit comprising a telephoto lens unit, the telephoto lens unit and the wide lens unit having respectively TTL/EFL ratios smaller and larger than 1 and defining separate telephoto and wide optical paths.

22 Claims, 15 Drawing Sheets



(51) **Int. Cl.**
G03B 17/00 (2006.01)
G02B 13/02 (2006.01)
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(52) **U.S. Cl.**
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(58) **Field of Classification Search**
CPC G02B 9/34; G02B 9/60; H04N 5/2258; H04N 5/2253; H04N 5/2254
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2,441,093 A 5/1948 Aklin
3,388,956 A 6/1968 Eggert et al.
3,524,700 A 8/1970 Eggert et al.
3,864,027 A 2/1975 Harada
3,942,876 A 3/1976 Betensky
4,134,645 A 1/1979 Sugiyama et al.
4,139,264 A * 2/1979 Takahashi G02B 13/02 359/746
4,199,785 A 4/1980 McCullough et al.
4,338,001 A 7/1982 Matsui
4,465,345 A 8/1984 Yazawa
5,000,551 A 3/1991 Shibayama
5,005,083 A 4/1991 Grage et al.
5,032,917 A 7/1991 Aschwanden
5,051,830 A 9/1991 von Hoessle
5,172,235 A 12/1992 Wilm et al.
5,248,971 A 9/1993 Mandl
5,287,093 A 2/1994 Amano et al.
5,436,660 A 7/1995 Sakamoto
5,444,478 A 8/1995 Lelong et al.
5,459,520 A 10/1995 Sasaki
5,657,402 A 8/1997 Bender et al.
5,682,198 A 10/1997 Katayama et al.
5,768,443 A 6/1998 Michael et al.
5,926,190 A 7/1999 Turkowski et al.
5,940,641 A 8/1999 McIntyre et al.
5,982,951 A 11/1999 Katayama et al.
6,101,334 A 8/2000 Fantone
6,128,416 A 10/2000 Oura
6,148,120 A 11/2000 Sussman
6,208,765 B1 3/2001 Bergen
6,268,611 B1 7/2001 Pettersson et al.
6,549,215 B2 4/2003 Jouppi
6,611,289 B1 8/2003 Yu et al.
6,643,416 B1 11/2003 Daniels et al.
6,650,368 B1 11/2003 Doron
6,654,180 B2 11/2003 Ori
6,680,748 B1 1/2004 Monti
6,714,665 B1 3/2004 Hanna et al.
6,724,421 B1 4/2004 Glatt
6,738,073 B2 5/2004 Park et al.
6,741,250 B1 5/2004 Furlan et al.
6,750,903 B1 6/2004 Miyatake et al.
6,778,207 B1 8/2004 Lee et al.
7,002,583 B2 2/2006 Rabb, III
7,015,954 B1 3/2006 Foote et al.
7,038,716 B2 5/2006 Klein et al.
7,187,504 B2 3/2007 Horiuchi
7,199,348 B2 4/2007 Olsen et al.
7,206,136 B2 4/2007 Labaziewicz et al.
7,248,294 B2 7/2007 Slatter
7,256,944 B2 8/2007 Labaziewicz et al.
7,305,180 B2 12/2007 Labaziewicz et al.
7,339,621 B2 3/2008 Fortier
7,346,217 B1 3/2008 Gold, Jr.
7,365,793 B2 4/2008 Cheatle et al.
7,411,610 B2 8/2008 Doyle
7,424,218 B2 9/2008 Baudisch et al.
7,509,041 B2 3/2009 Hosono
7,515,351 B2 4/2009 Chen et al.
7,533,819 B2 5/2009 Barkan et al.
7,564,635 B1 7/2009 Tang
7,619,683 B2 11/2009 Davis
7,643,225 B1 1/2010 Tsai
7,660,049 B2 2/2010 Tang
7,684,128 B2 3/2010 Tang
7,688,523 B2 3/2010 Sano
7,692,877 B2 4/2010 Tang et al.
7,697,220 B2 4/2010 Iyama
7,738,016 B2 6/2010 Toyofuku
7,738,186 B2 6/2010 Chen et al.
7,773,121 B1 8/2010 Huntsberger et al.
7,777,972 B1 8/2010 Chen et al.
7,813,057 B2 10/2010 Lin
7,821,724 B2 10/2010 Tang et al.
7,826,149 B2 11/2010 Tang et al.
7,826,151 B2 11/2010 Tsai
7,869,142 B2 1/2011 Chen et al.
7,880,776 B2 2/2011 LeGall et al.
7,898,747 B2 3/2011 Tang
7,916,401 B2 3/2011 Chen et al.
7,918,398 B2 4/2011 Li et al.
7,957,075 B2 6/2011 Tang
7,957,076 B2 6/2011 Tang
7,957,079 B2 6/2011 Tang
7,961,406 B2 6/2011 Tang et al.
7,964,835 B2 6/2011 Olsen et al.
7,978,239 B2 7/2011 Deever et al.
8,000,031 B1 8/2011 Tsai
8,004,777 B2 8/2011 Souma
8,046,026 B2 10/2011 Koh
8,077,400 B2 12/2011 Tang
8,115,825 B2 2/2012 Culbert et al.
8,149,327 B2 4/2012 Lin et al.
8,149,523 B2 4/2012 Ozaki
8,154,610 B2 4/2012 Jo et al.
8,218,253 B2 7/2012 Tang
8,228,622 B2 7/2012 Tang
8,233,224 B2 7/2012 Chen
8,238,695 B1 8/2012 Davey et al.
8,253,843 B2 8/2012 Lin
8,274,552 B2 9/2012 Dahi et al.
8,279,537 B2 10/2012 Sato
8,363,337 B2 1/2013 Tang et al.
8,390,729 B2 3/2013 Long et al.
8,391,697 B2 3/2013 Cho et al.
8,395,851 B2 3/2013 Tang et al.
8,400,555 B1 3/2013 Georgiev et al.
8,400,717 B2 3/2013 Chen et al.
8,439,265 B2 5/2013 Ferren et al.
8,446,484 B2 5/2013 Muukki et al.
8,451,549 B2 5/2013 Yamanaka et al.
8,483,452 B2 7/2013 Ueda et al.
8,503,107 B2 8/2013 Chen et al.
8,514,491 B2 8/2013 Duparre
8,514,502 B2 8/2013 Chen
8,547,389 B2 10/2013 Hoppe et al.
8,553,106 B2 10/2013 Scarff
8,587,691 B2 11/2013 Takane
8,619,148 B1 12/2013 Watts et al.
8,780,465 B2 7/2014 Chae
8,803,990 B2 8/2014 Smith
8,810,923 B2 8/2014 Shinohara
8,854,745 B1 10/2014 Chen
8,958,164 B2 2/2015 Kwon et al.
8,976,255 B2 3/2015 Matsuoto et al.
9,019,387 B2 4/2015 Nakano
9,025,073 B2 5/2015 Attar et al.
9,025,077 B2 5/2015 Attar et al.
9,041,835 B2 5/2015 Honda
9,137,447 B2 9/2015 Shibuno
9,185,291 B1 11/2015 Shabtay et al.
9,215,377 B2 12/2015 Sokeila et al.
9,215,385 B2 12/2015 Luo
9,229,194 B2 1/2016 Yoneyama et al.
9,235,036 B2 1/2016 Kato et al.
9,270,875 B2 2/2016 Brisedoux et al.
9,279,957 B2 3/2016 Kanda et al.
9,286,680 B1 3/2016 Jiang et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

9,344,626	B2	5/2016	Silverstein et al.
9,360,671	B1	6/2016	Zhou
9,369,621	B2	6/2016	Malone et al.
9,413,930	B2	8/2016	Geerds
9,413,984	B2	8/2016	Attar et al.
9,420,180	B2	8/2016	Jin
9,438,792	B2	9/2016	Nakada et al.
9,485,432	B1	11/2016	Medasani et al.
9,488,802	B2	11/2016	Chen et al.
9,568,712	B2	2/2017	Dror et al.
9,578,257	B2	2/2017	Attar et al.
9,618,748	B2	4/2017	Munger et al.
9,678,310	B2	6/2017	Iwasaki et al.
9,681,057	B2	6/2017	Attar et al.
9,723,220	B2	8/2017	Sugie
9,736,365	B2	8/2017	Laroia
9,736,391	B2	8/2017	Du et al.
9,768,310	B2	9/2017	Ahn et al.
9,800,798	B2	10/2017	Ravirala et al.
9,817,213	B2	11/2017	Mercado
9,851,803	B2	12/2017	Fisher et al.
9,894,287	B2	2/2018	Qian et al.
9,900,522	B2	2/2018	Lu
9,927,600	B2	3/2018	Goldenberg et al.
2002/0005902	A1	1/2002	Yuen
2002/0063711	A1	5/2002	Park et al.
2002/0075258	A1	6/2002	Park et al.
2002/0122113	A1	9/2002	Foote
2003/0030729	A1	2/2003	Prentice et al.
2003/0093805	A1	5/2003	Gin
2003/0160886	A1	8/2003	Misawa et al.
2003/0202113	A1	10/2003	Yoshikawa
2004/0008773	A1	1/2004	Itokawa
2004/0017386	A1	1/2004	Liu et al.
2004/0027367	A1	2/2004	Pilu
2004/0061788	A1	4/2004	Bateman
2004/0240052	A1	12/2004	Minefuji et al.
2005/0013509	A1	1/2005	Samadani
2005/0046740	A1	3/2005	Davis
2005/0141103	A1	6/2005	Nishina
2005/0157184	A1	7/2005	Nakanishi et al.
2005/0168840	A1	8/2005	Kobayashi et al.
2005/0200718	A1	9/2005	Lee
2006/0054782	A1	3/2006	Olsen et al.
2006/0056056	A1	3/2006	Ahiska et al.
2006/0125937	A1	6/2006	LeGall et al.
2006/0170793	A1	8/2006	Pasquarette et al.
2006/0175549	A1	8/2006	Miller et al.
2006/0187310	A1	8/2006	Janson et al.
2006/0187312	A1*	8/2006	Labaziewicz H04N 5/225 348/218.1
2006/0187322	A1	8/2006	Janson et al.
2006/0187338	A1	8/2006	May et al.
2007/0024737	A1	2/2007	Nakamura et al.
2007/0177025	A1	8/2007	Kopet et al.
2007/0188653	A1	8/2007	Pollock et al.
2007/0189386	A1	8/2007	Imagawa et al.
2007/0229983	A1	10/2007	Saori
2007/0257184	A1	11/2007	Olsen et al.
2007/0285550	A1	12/2007	Son
2008/0017557	A1	1/2008	Witdouck
2008/0024614	A1	1/2008	Li et al.
2008/0025634	A1	1/2008	Border et al.
2008/0030592	A1	2/2008	Border et al.
2008/0030611	A1	2/2008	Jenkins
2008/0084484	A1	4/2008	Ochi et al.
2008/0117316	A1	5/2008	Orimoto
2008/0166115	A1	7/2008	Sachs et al.
2008/0218611	A1	9/2008	Parulski et al.
2008/0218612	A1	9/2008	Border et al.
2008/0218613	A1	9/2008	Janson et al.
2008/0219654	A1	9/2008	Border et al.
2008/0247055	A1	10/2008	Chang
2008/0304161	A1	12/2008	Souma
2009/0086074	A1	4/2009	Li et al.
2009/0122195	A1	5/2009	Van Baar et al.
2009/0122406	A1	5/2009	Rouvinen et al.
2009/0122423	A1	5/2009	Park et al.
2009/0128644	A1	5/2009	Camp et al.
2009/0219547	A1	9/2009	Kauhanen et al.
2009/0252484	A1	10/2009	Hasuda et al.
2009/0295949	A1	12/2009	Ojala
2010/0013906	A1	1/2010	Border et al.
2010/0020221	A1	1/2010	Tupman et al.
2010/0060746	A9	3/2010	Olsen et al.
2010/0103194	A1	4/2010	Chen et al.
2010/0238327	A1	9/2010	Griffith et al.
2010/0283842	A1	11/2010	Guissin et al.
2010/0302640	A1*	12/2010	Take G02B 15/173 359/557
2010/0328471	A1	12/2010	Boland et al.
2011/0001838	A1	1/2011	Lee
2011/0064327	A1	3/2011	Dagher et al.
2011/0080487	A1	4/2011	Venkataraman et al.
2011/0115965	A1	5/2011	Engelhardt et al.
2011/0128288	A1	6/2011	Petrou et al.
2011/0164172	A1	7/2011	Shintani et al.
2011/0229054	A1	9/2011	Weston et al.
2011/0234853	A1	9/2011	Hayashi et al.
2011/0234881	A1	9/2011	Wakabayashi et al.
2011/0242286	A1	10/2011	Pace et al.
2011/0242355	A1	10/2011	Goma et al.
2012/0026366	A1	2/2012	Golan et al.
2012/0062780	A1	3/2012	Morihisa
2012/0069235	A1	3/2012	Imai
2012/0075489	A1	3/2012	Nishihara
2012/0092777	A1	4/2012	Tochigi et al.
2012/0105579	A1	5/2012	Jeon et al.
2012/0105708	A1	5/2012	Hagiwara
2012/0113515	A1	5/2012	Karn et al.
2012/0154929	A1	6/2012	Tsai et al.
2012/0196648	A1	8/2012	Havens et al.
2012/0229663	A1	9/2012	Nelson et al.
2012/0249815	A1	10/2012	Bohn et al.
2012/0287315	A1	11/2012	Huang et al.
2012/0320467	A1	12/2012	Baik et al.
2013/0002928	A1	1/2013	Imai
2013/0093842	A1	4/2013	Yahata
2013/0135445	A1	5/2013	Dahi et al.
2013/0182150	A1	7/2013	Asakura
2013/0201360	A1	8/2013	Song
2013/0202273	A1	8/2013	Ouedraogo et al.
2013/0208178	A1	8/2013	Park
2013/0235224	A1	9/2013	Park et al.
2013/0250150	A1	9/2013	Malone et al.
2013/0258044	A1	10/2013	Betts-LaCroix
2013/0286488	A1	10/2013	Chae
2013/0321668	A1	12/2013	Kamath
2014/0022436	A1	1/2014	Kim et al.
2014/0049615	A1	2/2014	Uwagawa
2014/0118584	A1	5/2014	Lee et al.
2014/0192238	A1	7/2014	Attar et al.
2014/0192253	A1	7/2014	Laroia
2014/0204480	A1	7/2014	Jo et al.
2014/0285907	A1	9/2014	Tang et al.
2014/0293453	A1	10/2014	Ogino et al.
2014/0313316	A1	10/2014	Olsson et al.
2014/0362242	A1	12/2014	Takizawa
2014/0362274	A1	12/2014	Christie et al.
2015/0002683	A1	1/2015	Hu et al.
2015/0042870	A1	2/2015	Chan et al.
2015/0092066	A1	4/2015	Geiss et al.
2015/0116569	A1	4/2015	Mercado
2015/0154776	A1	6/2015	Zhang et al.
2015/0162048	A1	6/2015	Hirata et al.
2015/0195458	A1	7/2015	Nakayama et al.
2015/0215516	A1	7/2015	Dolgin
2015/0237280	A1	8/2015	Choi et al.
2015/0242994	A1	8/2015	Shen
2015/0253647	A1	9/2015	Mercado
2015/0271471	A1	9/2015	Hsieh et al.
2015/0316744	A1	11/2015	Chen
2015/0334309	A1	11/2015	Peng et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2015/0370039	A1*	12/2015	Bone	G02B 13/004 359/715
2016/0044250	A1	2/2016	Shabtay et al.	
2016/0070088	A1	3/2016	Koguchi	
2016/0085089	A1	3/2016	Mercado	
2016/0154202	A1	6/2016	Wippermann et al.	
2016/0154204	A1	6/2016	Lim et al.	
2016/0187630	A1*	6/2016	Choi	G02B 17/086 359/729
2016/0187631	A1	6/2016	Choi et al.	
2016/0212358	A1	7/2016	Shikata	
2016/0301840	A1	10/2016	Du et al.	
2016/0313537	A1	10/2016	Mercado	
2016/0353012	A1	12/2016	Kao et al.	
2017/0019616	A1	1/2017	Zhu et al.	
2017/0102522	A1	4/2017	Jo	
2017/0115471	A1	4/2017	Shinohara	
2017/0214846	A1	7/2017	Du et al.	
2017/0214866	A1	7/2017	Zhu et al.	
2017/0289458	A1	10/2017	Song et al.	
2018/0120674	A1	5/2018	Avivi et al.	
2018/0150973	A1	5/2018	Tang et al.	
2018/0224630	A1	8/2018	Lee et al.	
2018/0241922	A1	8/2018	Baldwin et al.	
2018/0295292	A1	10/2018	Lee et al.	

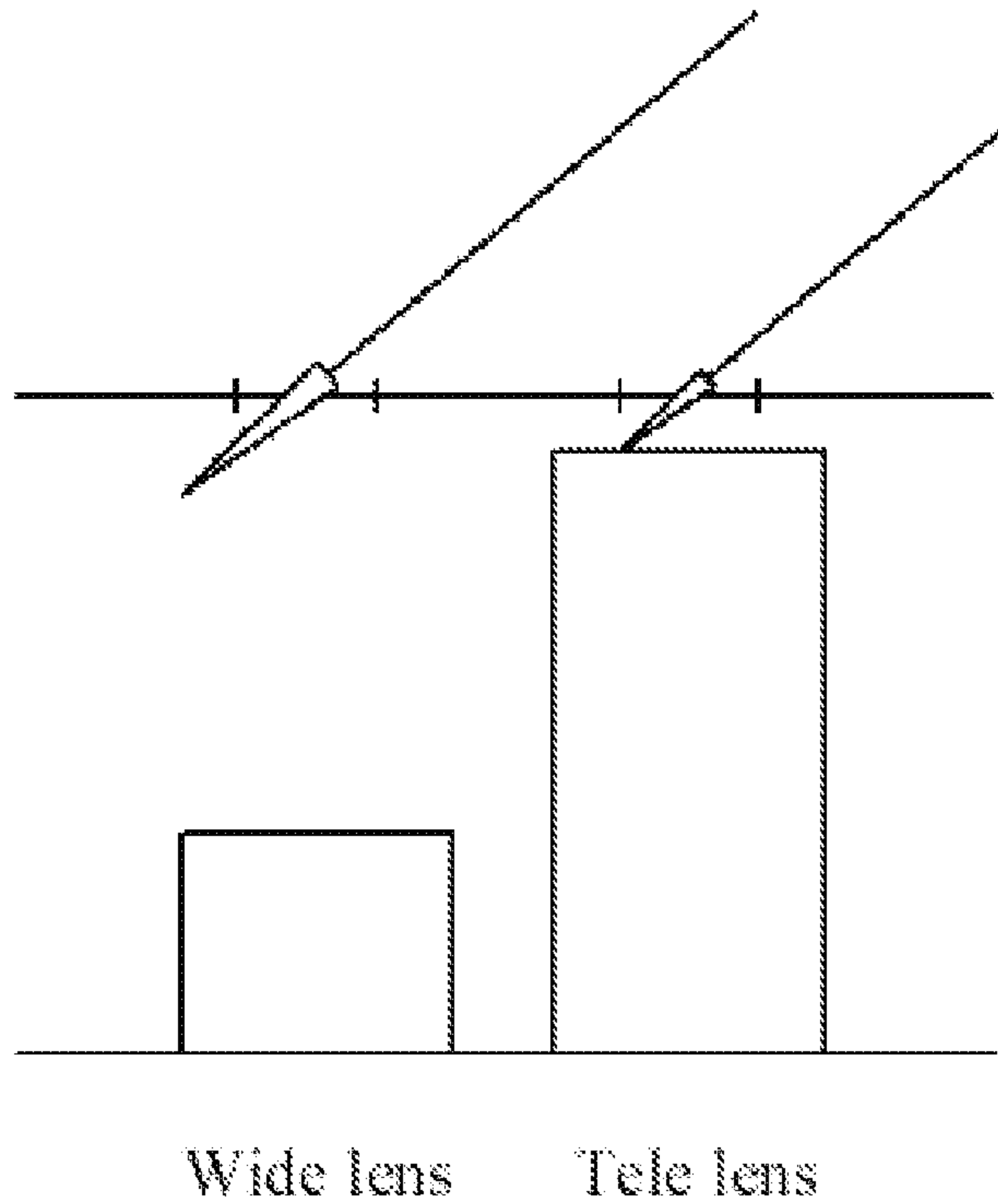
FOREIGN PATENT DOCUMENTS

CN	104297906	A	1/2015
EP	1536633	A1	6/2005
EP	2523450	A1	11/2012
JP	S54157620	A	12/1979
JP	S59121015	A	7/1984
JP	H07318864	A	12/1995
JP	2004133054	A	4/2004
JP	2007228006	A	9/2007
JP	2007306282	A	11/2007
JP	2008076485	A	4/2008
JP	2012203234	A	10/2012
JP	2013106289	A	5/2013
KR	20140014787	A	2/2014
KR	20140023552	A	2/2014
WO	2013058111	A1	4/2013
WO	2013063097	A1	5/2013
WO	2014/199338	A2	12/2014
WO	2014/083489	A2	6/2015

OTHER PUBLICATIONS

Consumer Electronic Optics: How small a lens can be? The case of panomorph lenses, Thibault et al., Sep. 2014, 7 pages.
Optical design of camera optics for mobile phones, Steinich et al., 2012, pp. 51-58 (8 pages).
The Optics of Miniature Digital Camera Modules, Bareau et al., 2006, 11 pages.
Modeling and measuring liquid crystal tunable lenses, Peter P. Clark, 2014, 7 pages.
Mobile Platform Optical Design, Peter P. Clark, 2014, 7 pages.
Statistical Modeling and Performance Characterization of a Real-Time Dual Camera Surveillance System, Greienhagen et al., Publisher: IEEE, 2000, 8 pages.
Dual camera intelligent sensor for high definition 360 degrees surveillance, Scotti et al., Publisher: IET, May 9, 2000, 8 pages.
Dual-sensor foveated imaging system, Hua et al., Publisher: Optical Society of America, Jan. 14, 2008, 11 pages.
Defocus Video Matting, McGuire et al., Publisher: ACM SIGGRAPH, Jul. 31, 2005, 11 pages.
Compact multi-aperture imaging with high angular resolution, Santacana et al., Publisher: Optical Society of America, 2015, 10 pages.
Multi-Aperture Photography, Green et al., Publisher: Mitsubishi Electric Research Laboratories, Inc., Jul. 2007, 10 pages.
Multispectral Bilateral Video Fusion, Bennett et al., Publisher: IEEE, May 2007, 10 pages.
Super-resolution imaging using a camera array, Santacana et al., Publisher: Optical Society of America, 2014, 6 pages.
Optical Splitting Trees for High-Precision Monocular Imaging, McGuire et al., Publisher: IEEE, 2007, 11 pages.
High Performance Imaging Using Large Camera Arrays, Wilburn et al., Publisher: Association for Computing Machinery, Inc., 2005, 12 pages.
Superimposed multi-resolution imaging, Carles et al., Publisher: Optical Society of America, 2017, 13 pages.
Viewfinder Alignment, Adams et al., Publisher: Eurographics, 2008, 10 pages.
Dual-Camera System for Multi-Level Activity Recognition, Bodor et al., Publisher: IEEE, Oct. 2014, 6 pages.
Engineered to the task: Why camera-phone cameras are different, Giles Humpston, Publisher: Solid State Technology, Jun. 2009, 3 pages.
International Search Report and Written Opinion issued in related PCT patent application PCT/IB2015/050044 dated Jul. 7, 2015. 8 pages.

* cited by examiner



KNOWN ART

FIG. 1A

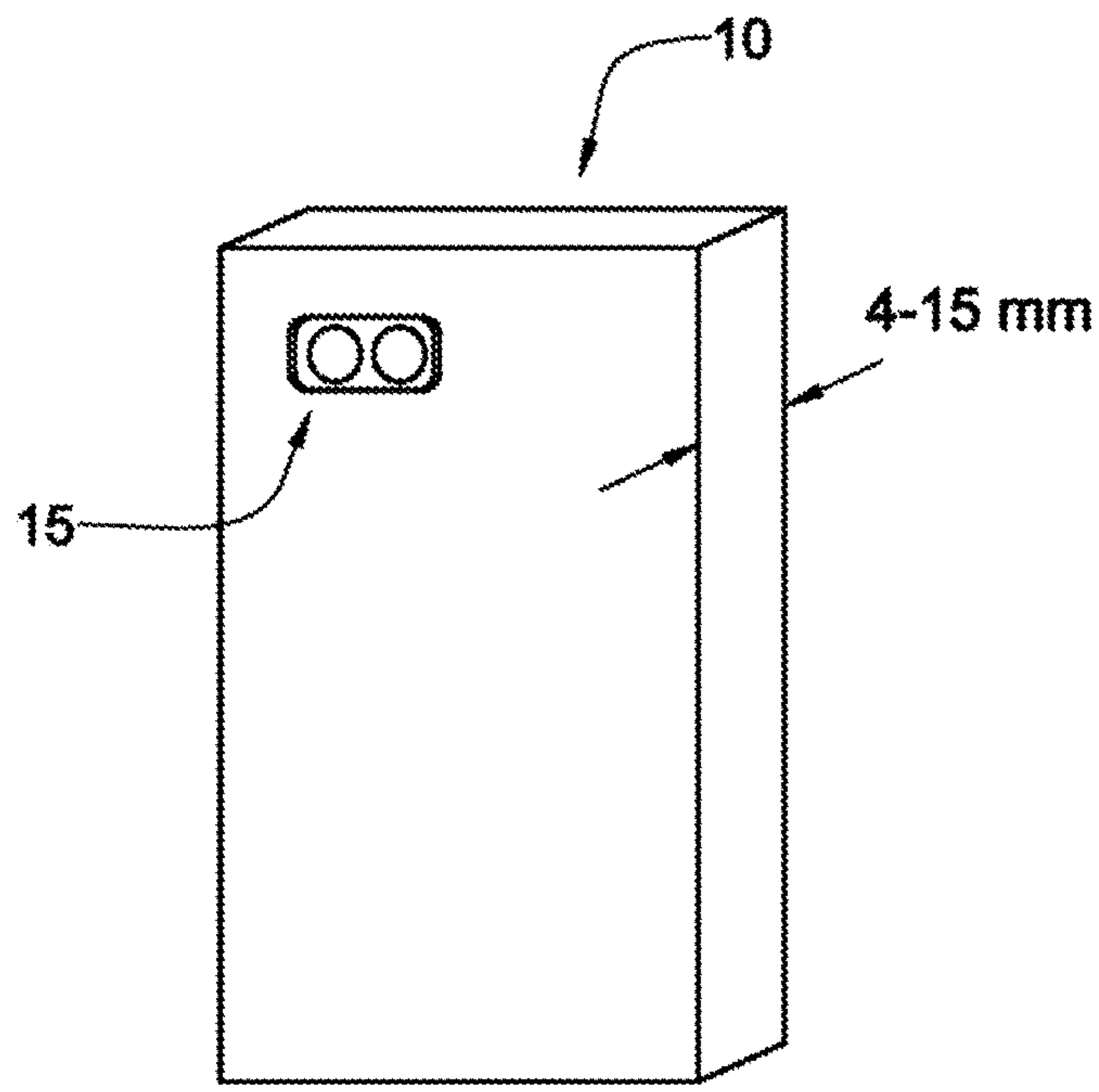


FIG. 1B

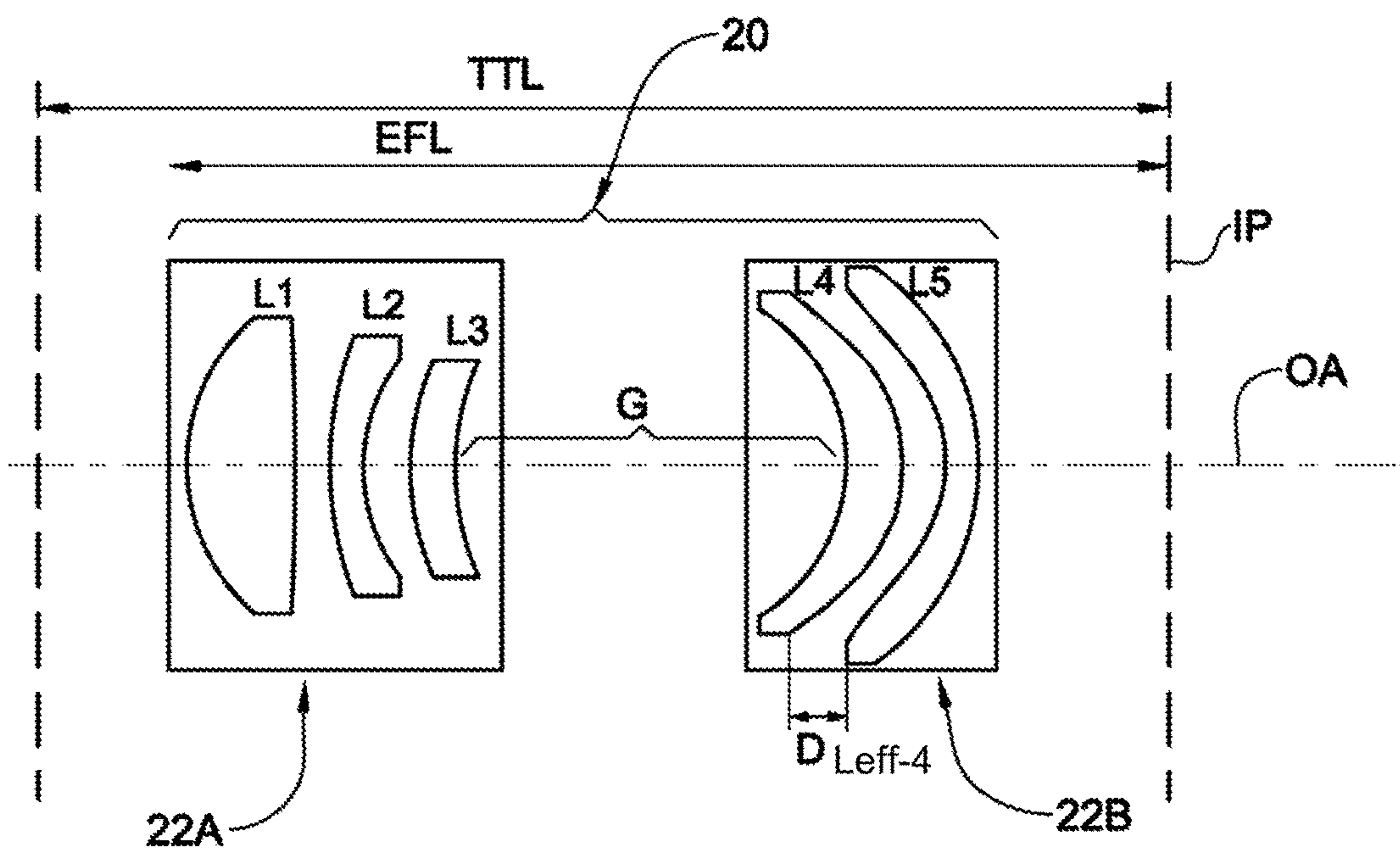
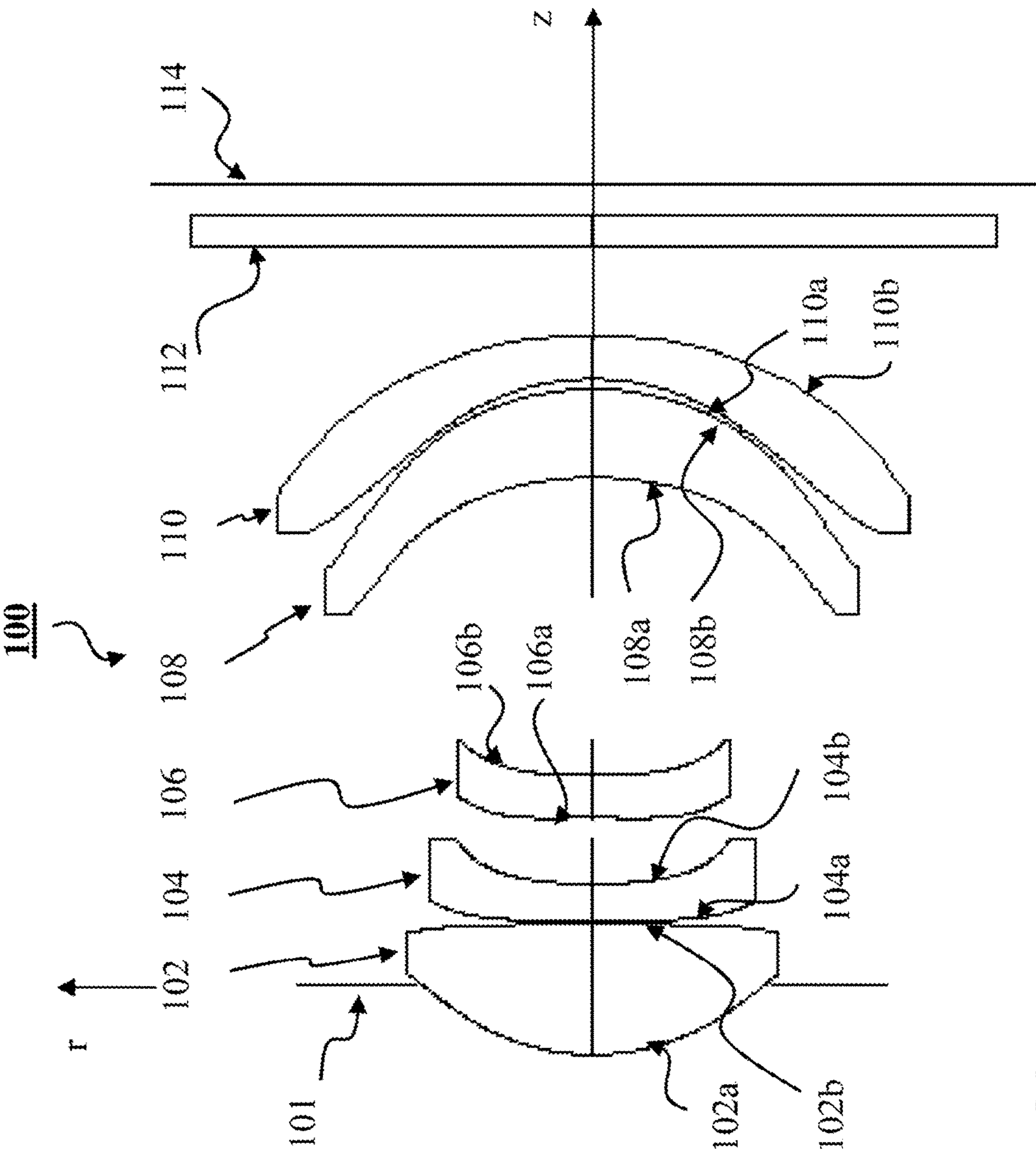


FIG. 1C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106b
104
104a
104b
102
102a
102b
101

FIG. 2A

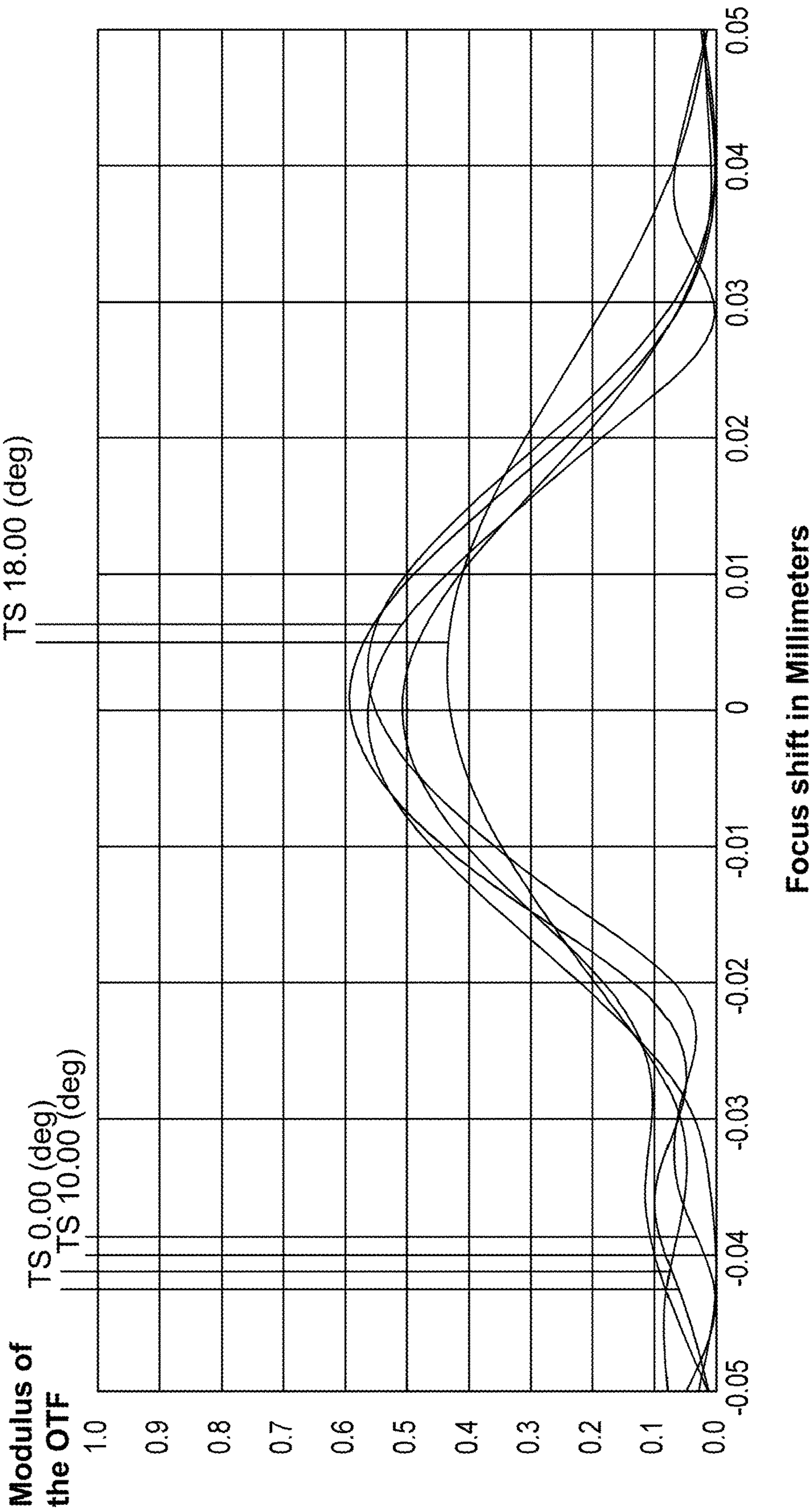

Modulus of the OTF
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
TS 0.00 (deg)
TS 10.00 (deg)
TS 18.00 (deg)
-0.05
-0.04
-0.03
-0.02
-0.01
0
0.01
0.02
0.03
0.04
0.05
Focus shift in Millimeters

FIG. 2B

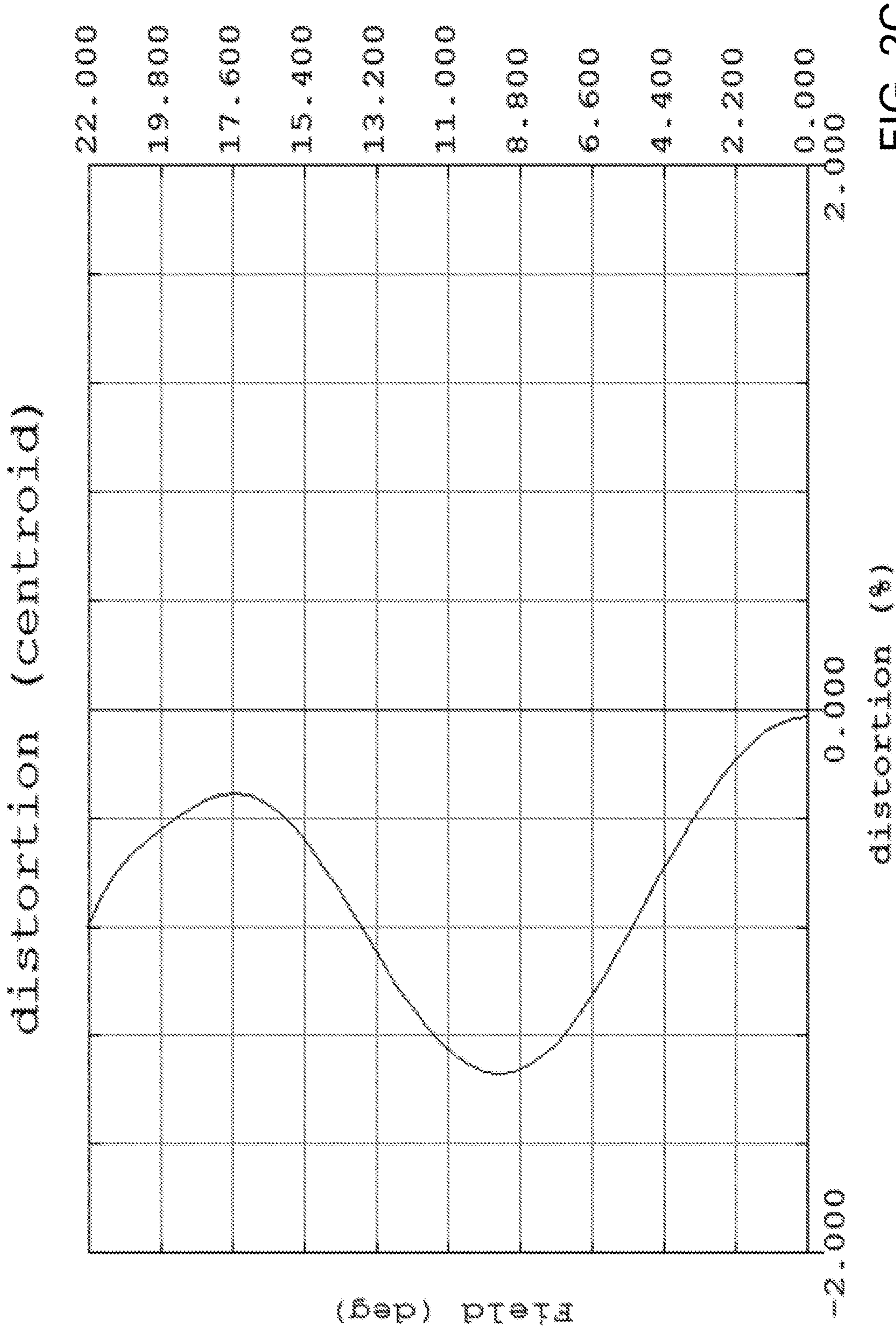

distortion (centroid)
22.000
19.800
17.600
15.400
13.200
11.000
8.800
6.600
4.400
2.200
0.000
2.000
0.000
-2.000
Field (deg)
distortion (%)

FIG. 2C

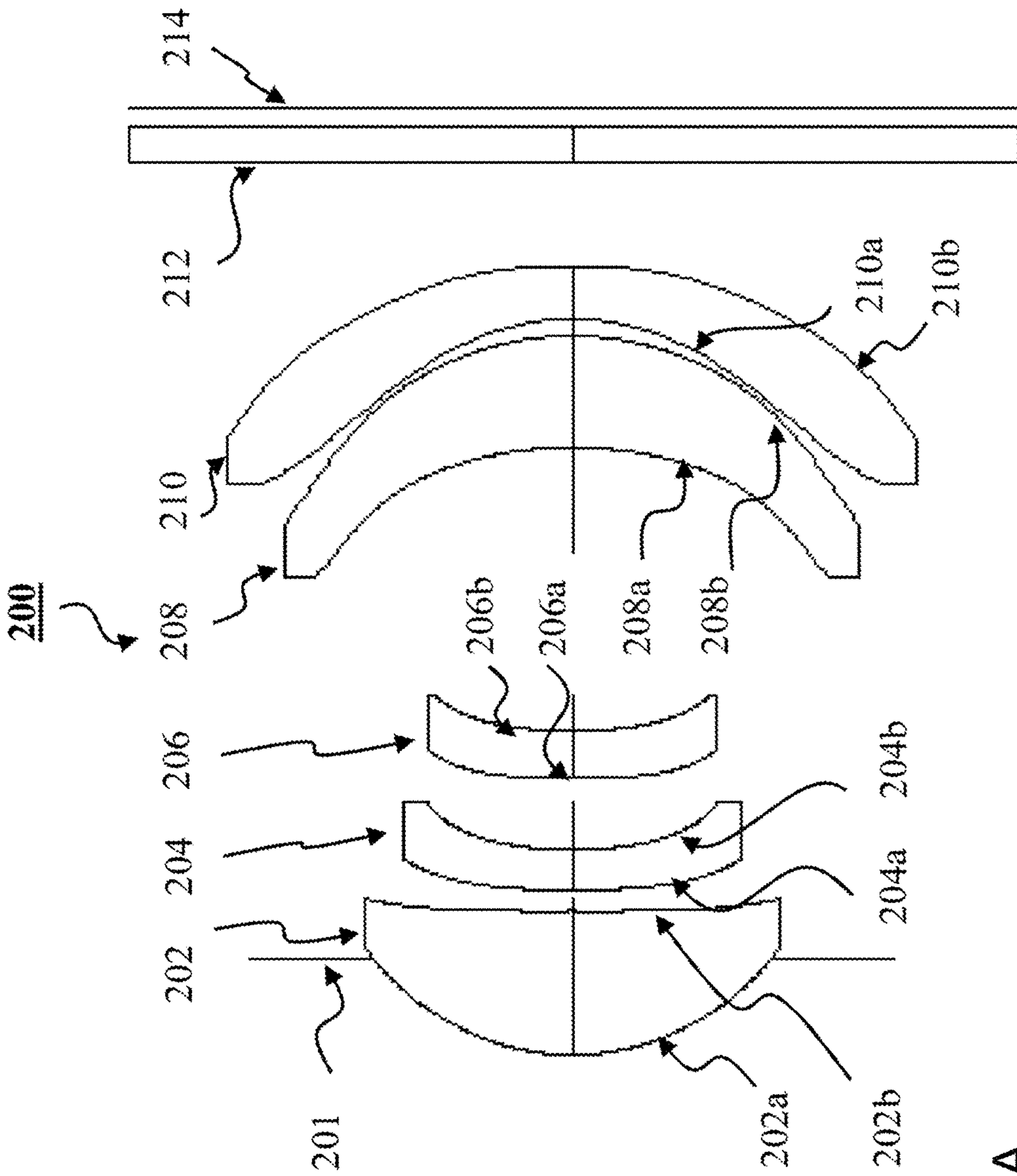
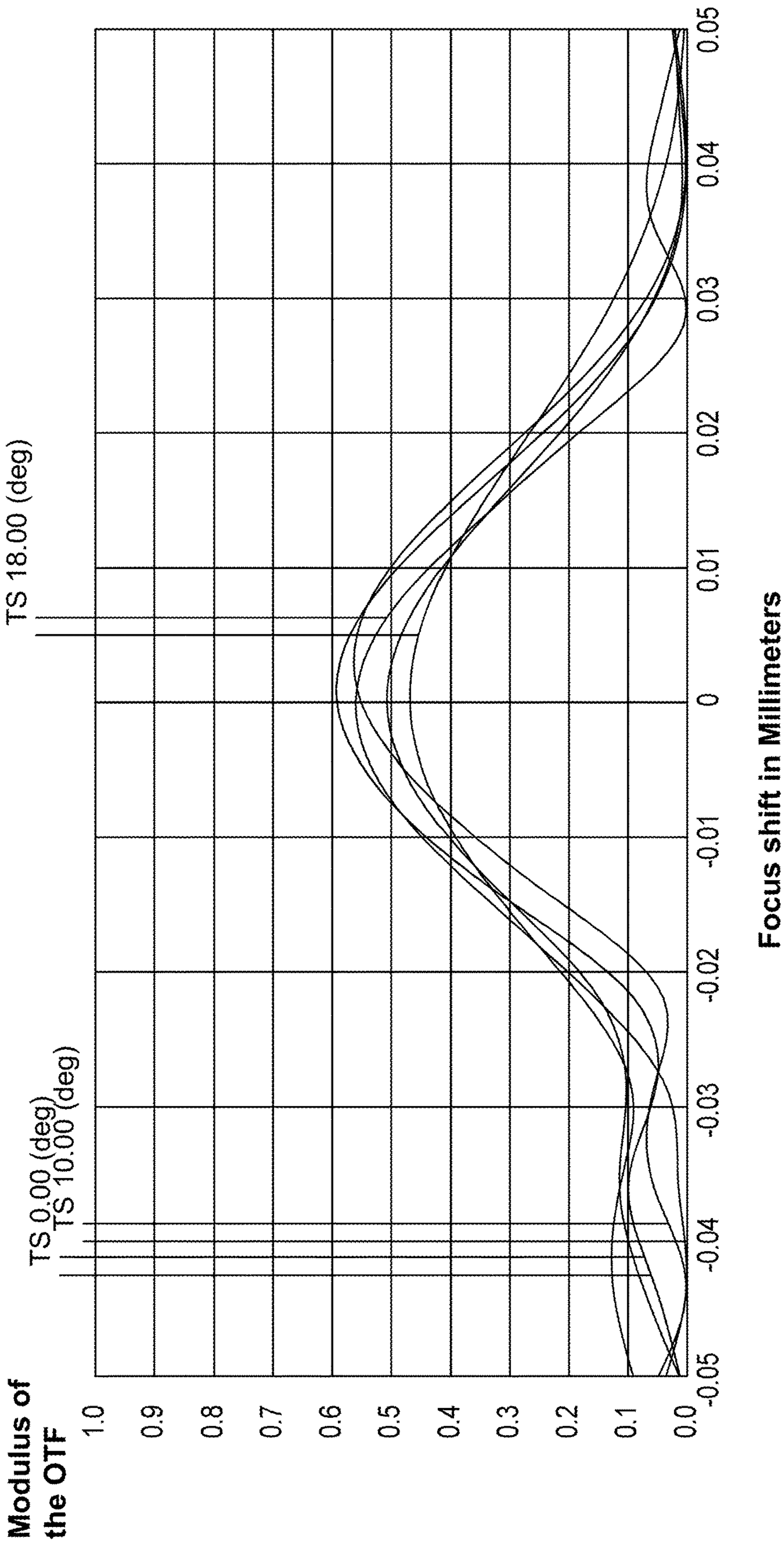

200
214
212
210
210a
210b
208
208a
208b
206
206a
206b
204
204a
204b
202
202a
202b
201

FIG. 3A



Modulus of the OTF
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.05
-0.04
-0.03
-0.02
-0.01
0
0.01
0.02
0.03
0.04
0.05
Focus shift in Millimeters
TS 0.00 (deg)
TS 10.00 (deg)
TS 18.00 (deg)

FIG. 3B

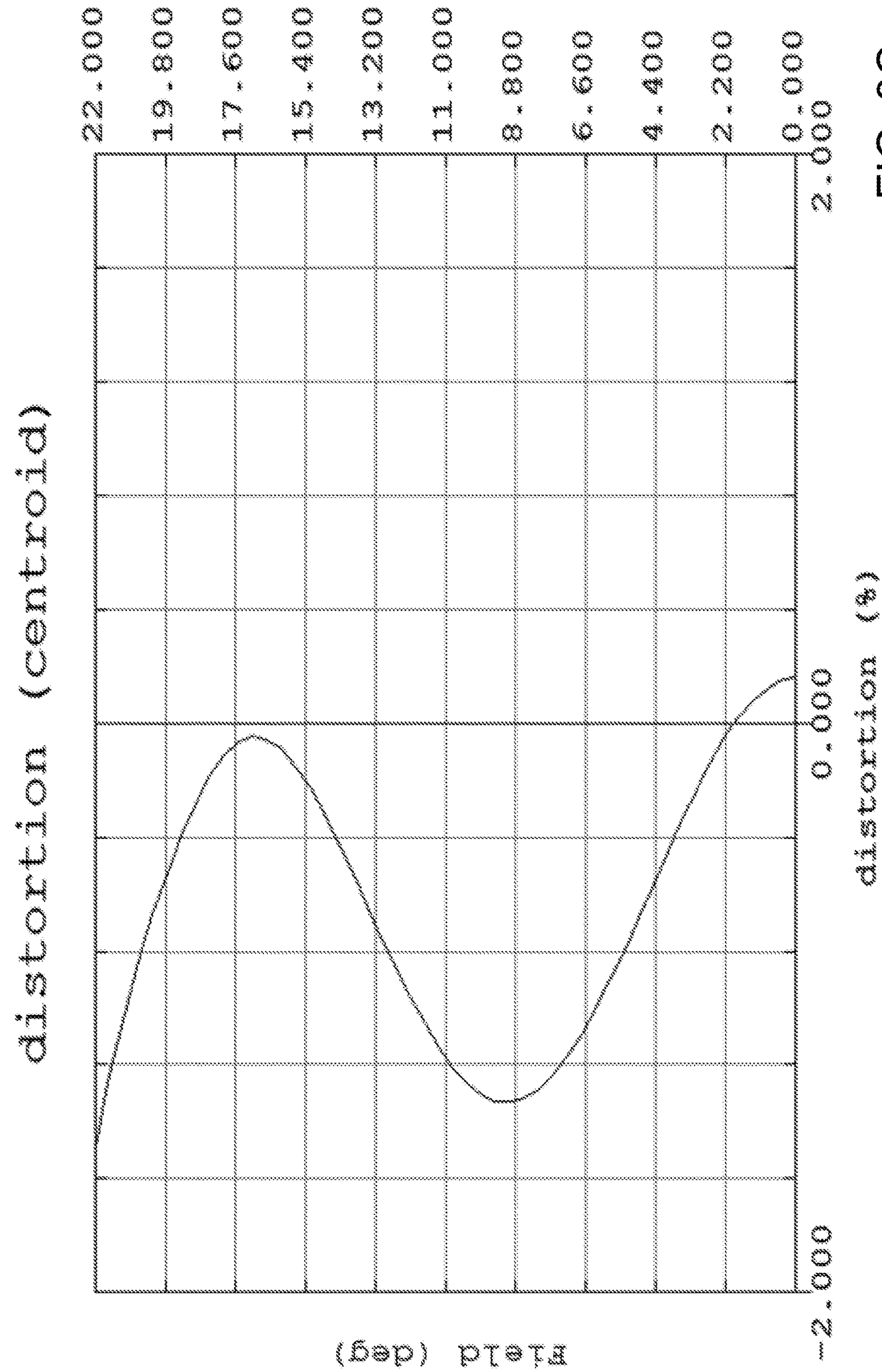

distortion (centroid)
Field (deg)
22.000
19.800
17.600
15.400
13.200
11.000
8.800
6.600
4.400
2.200
0.000
-2.000
0.000
2.000
distortion (%)

FIG. 3C

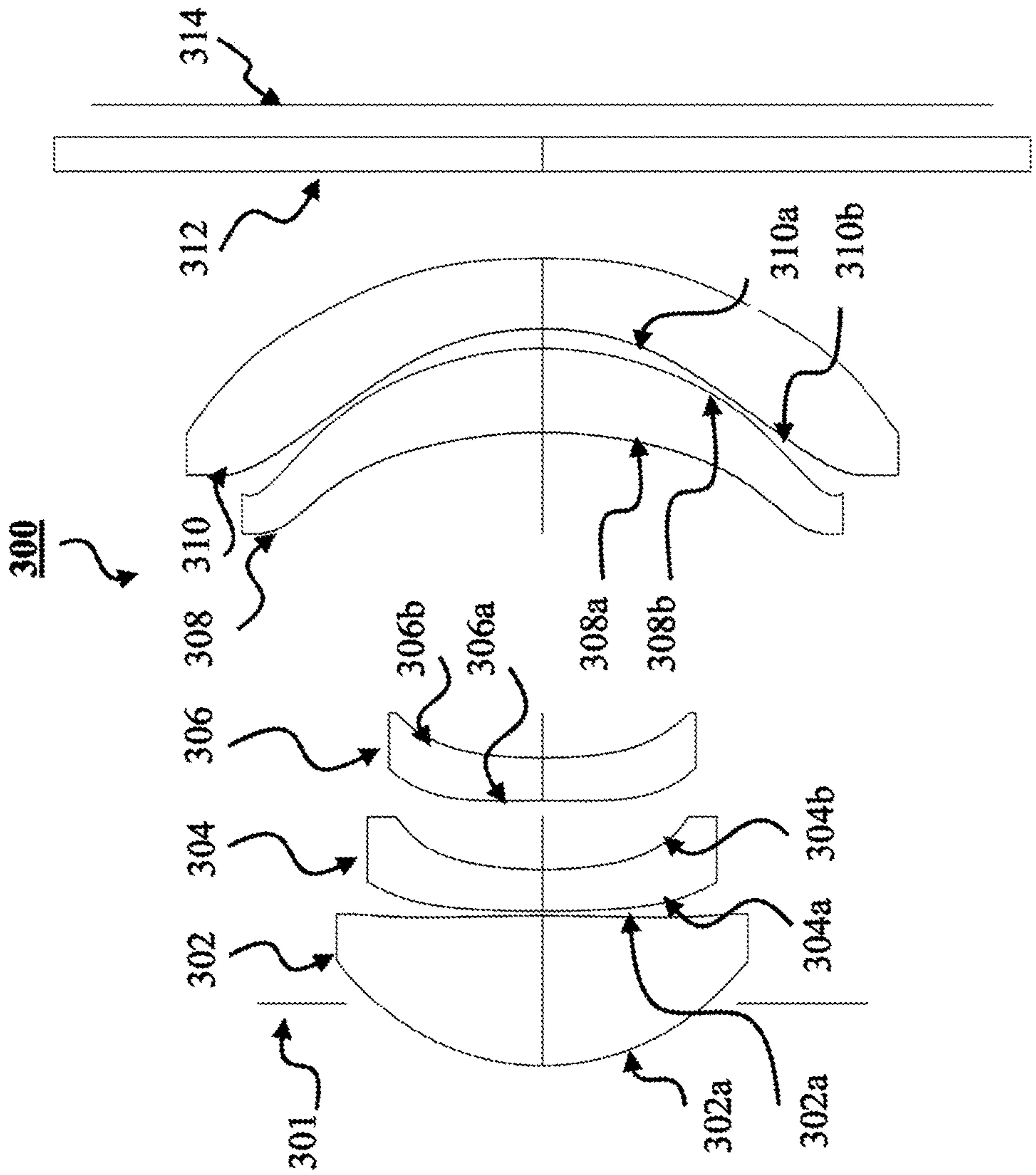

300
301
302
302a
302a
304
304a
304b
306
306a
306b
308
308a
308b
310
310a
310b
312
314

FIG. 4A

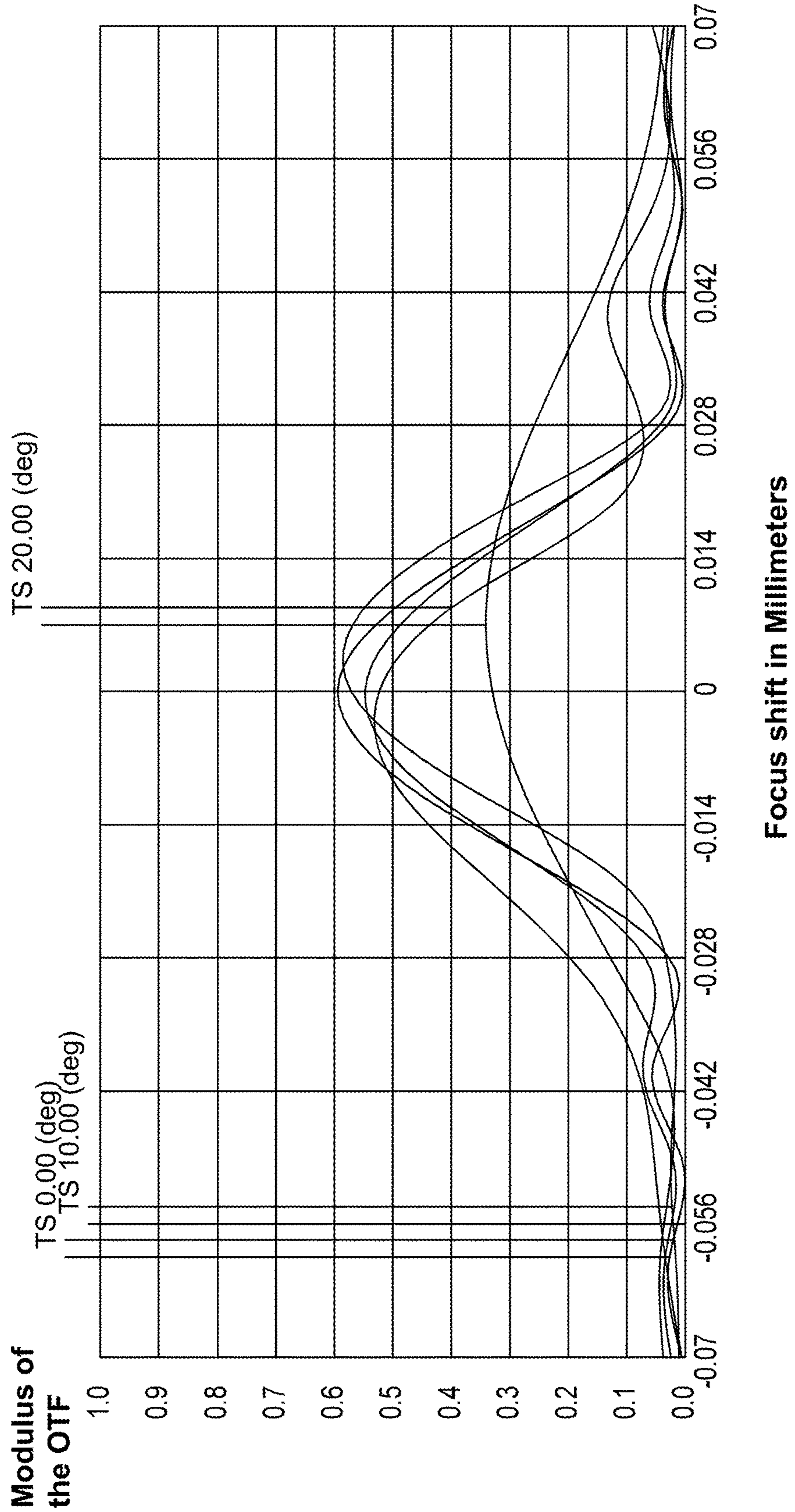

Modulus of the OTF
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
TS 0.00 (deg)
TS 10.00 (deg)
TS 20.00 (deg)
-0.07
-0.056
-0.042
-0.028
-0.014
0
0.014
0.028
0.042
0.056
0.07
Focus shift in Millimeters

FIG. 4B

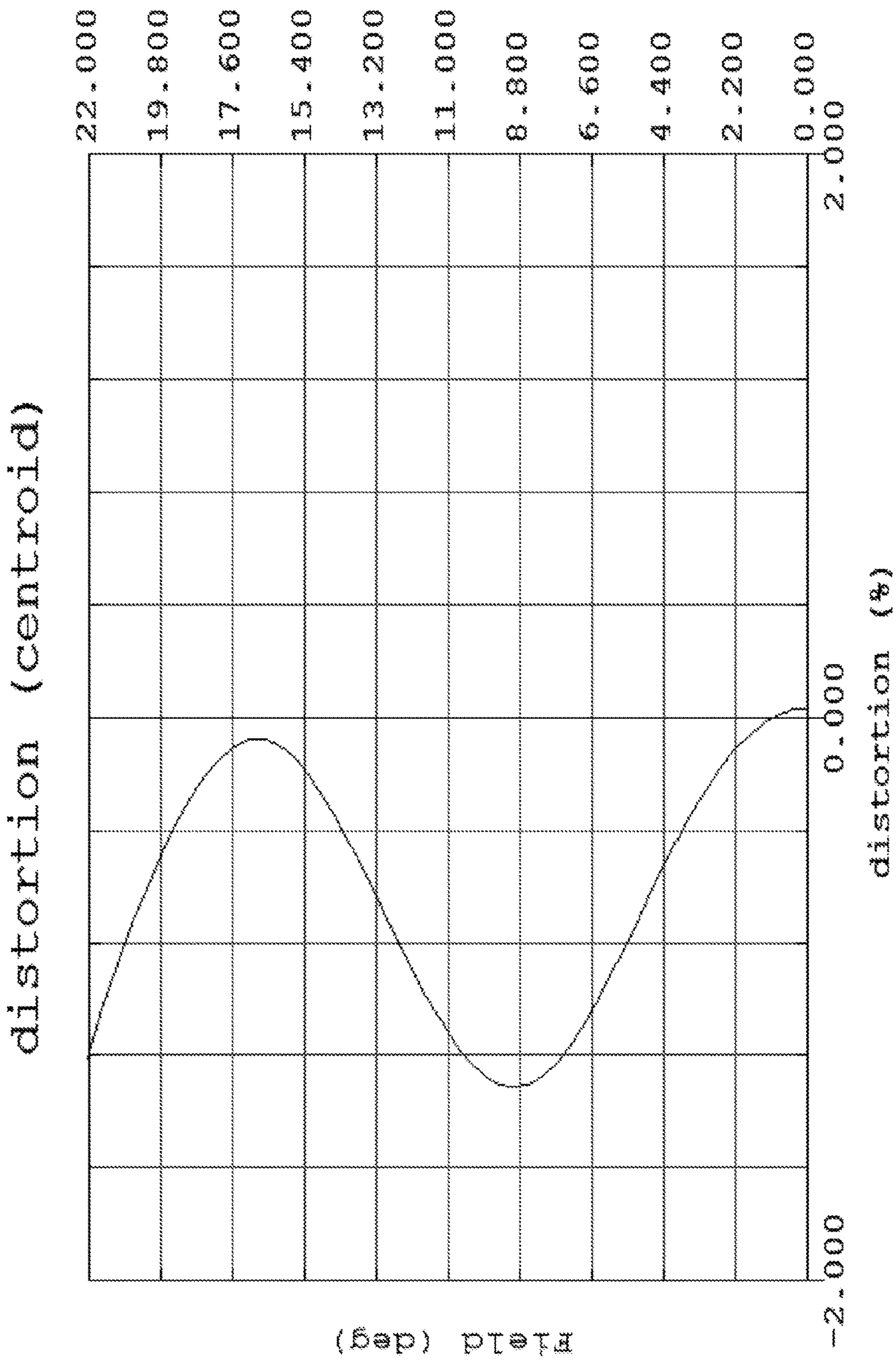

distortion (centroid)
22.000
19.800
17.600
15.400
13.200
11.000
8.800
6.600
4.400
2.200
0.000
-2.000
0.000
2.000
distortion (%)
Field (deg)

FIG. 4C

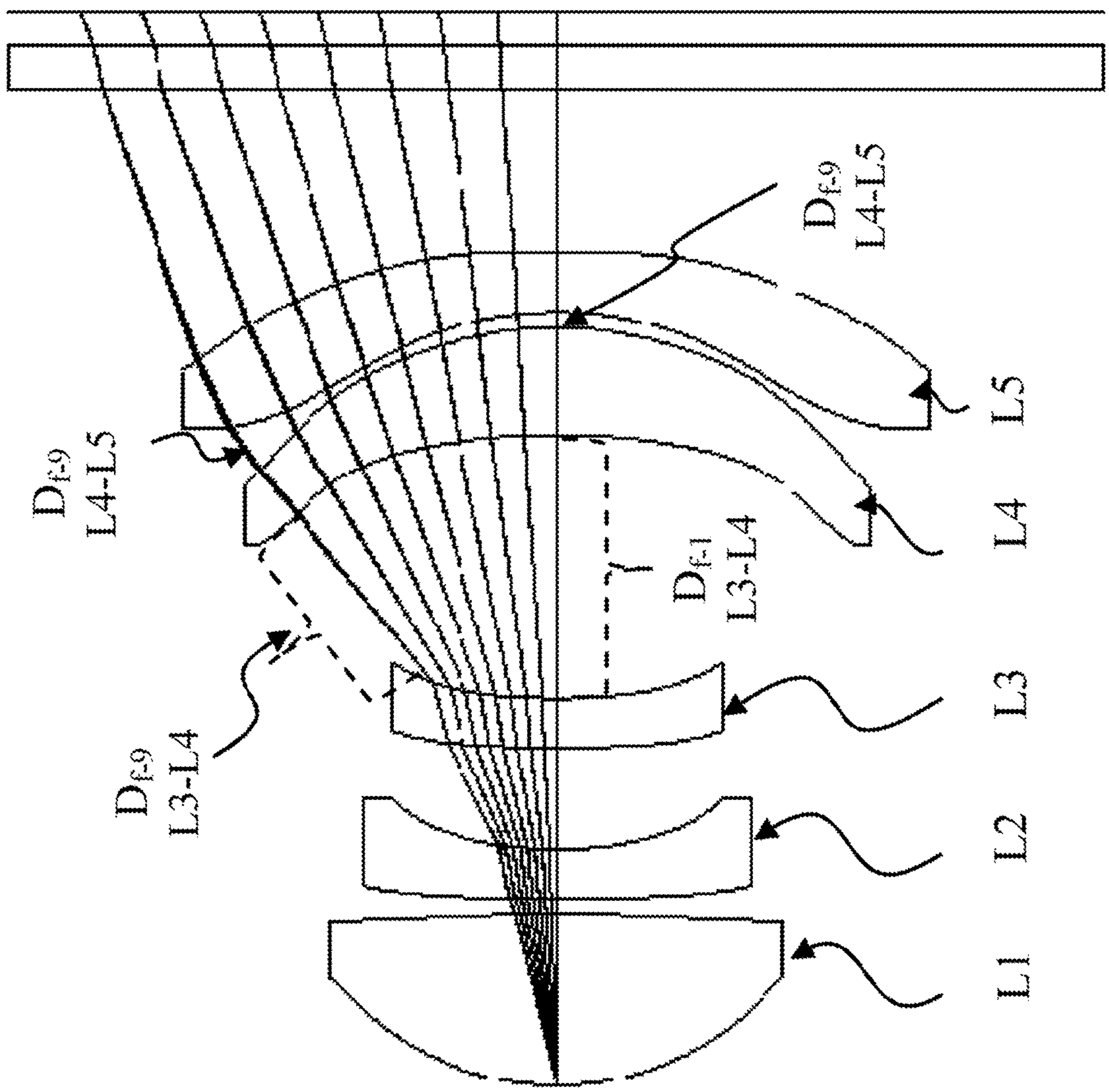
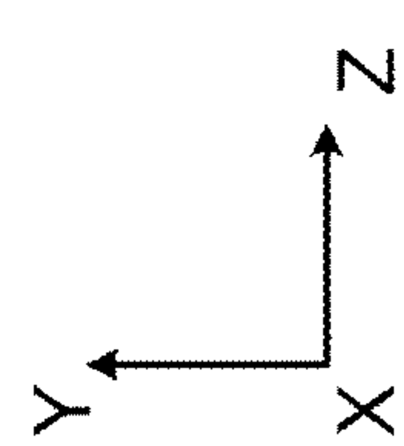


FIG. 5



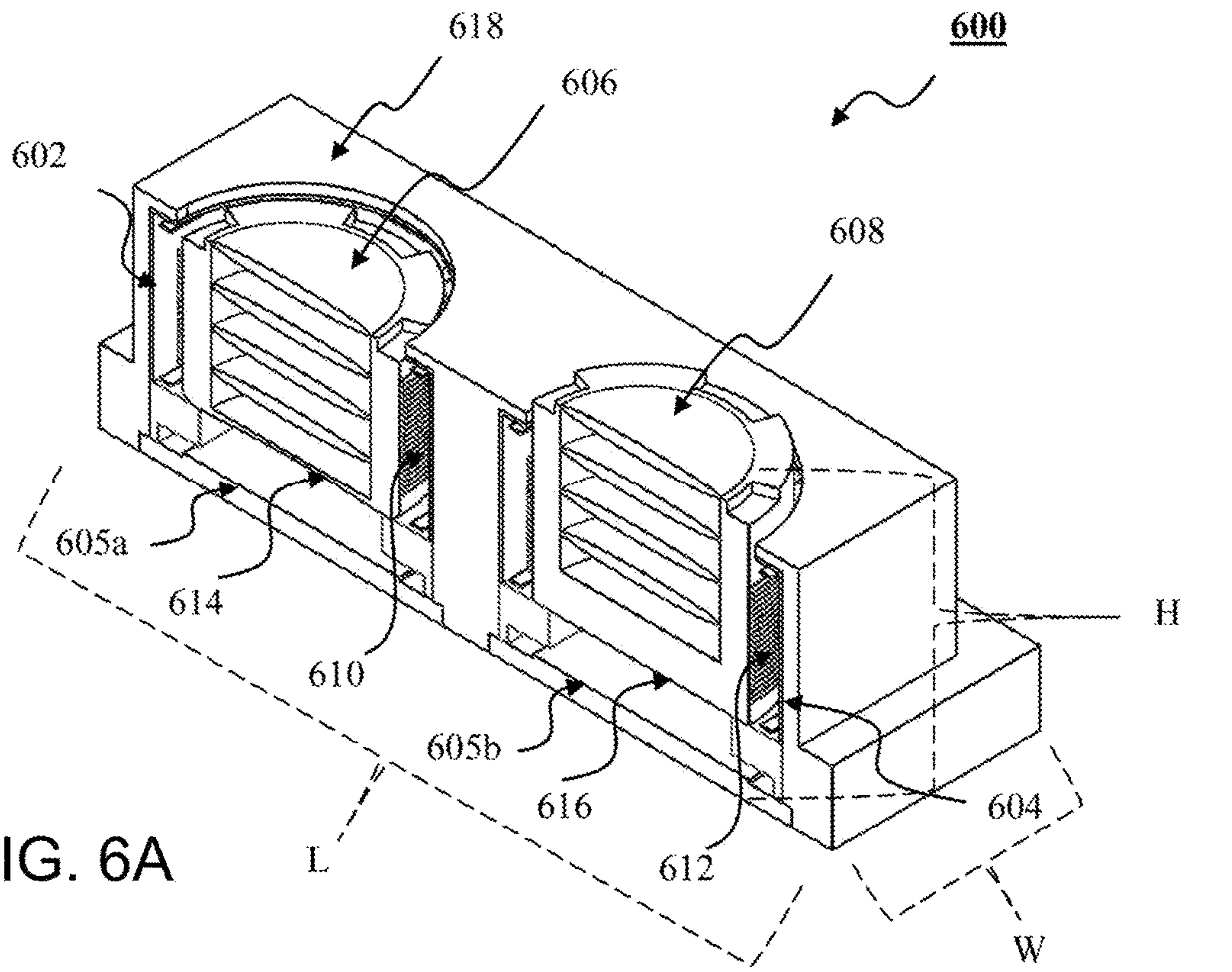

600
618
606
602
608
605a
614
610
605b
616
612
604
H
L
W

FIG. 6A

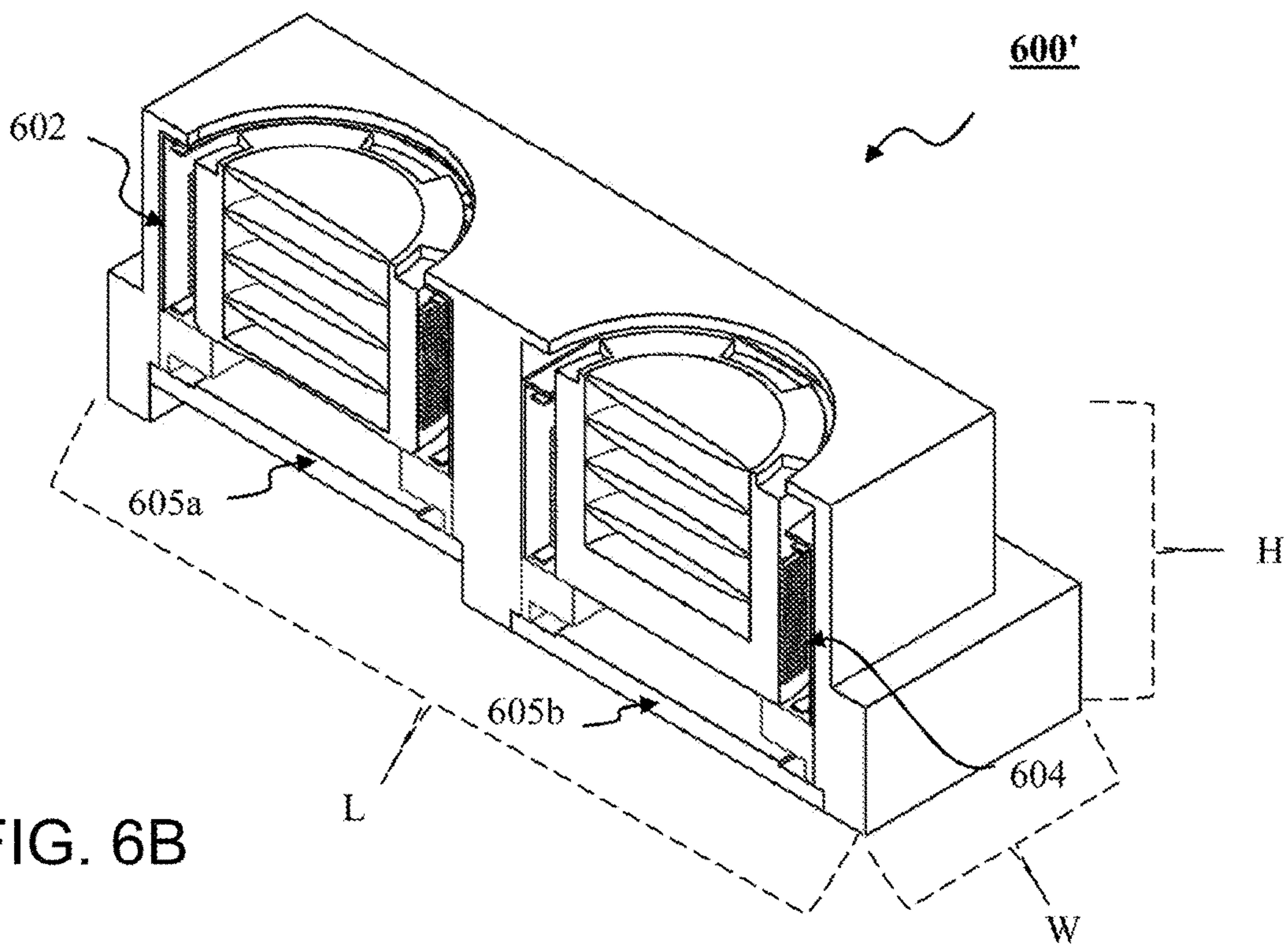

600'
602
605a
605b
604
H
L
W

FIG. 6B

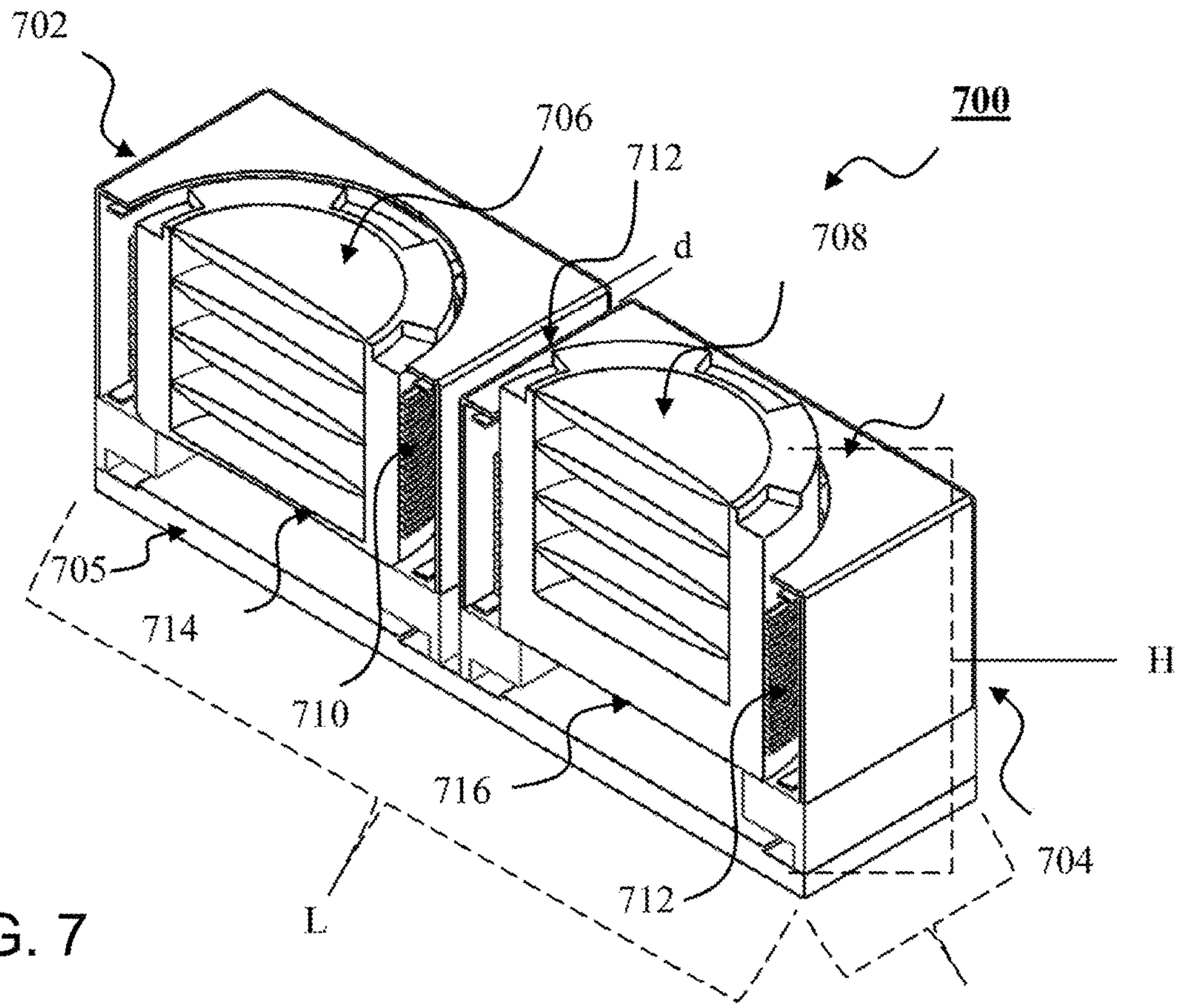

702
700
706
712
d
708
705
714
710
716
H
704
712
L

FIG. 7

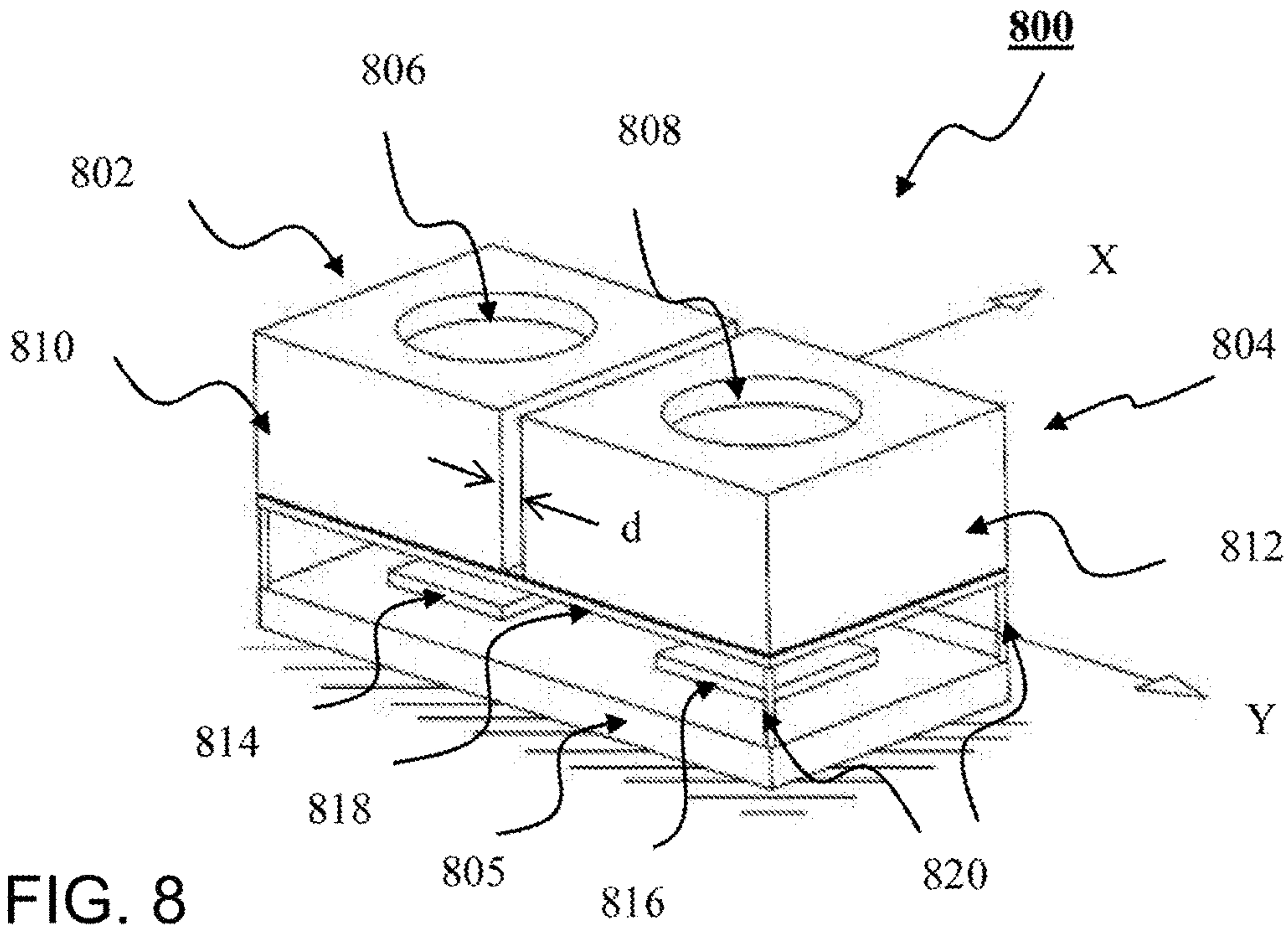

800
806
808
802
X
810
804
d
812
814
818
805
816
820
Y

FIG. 8

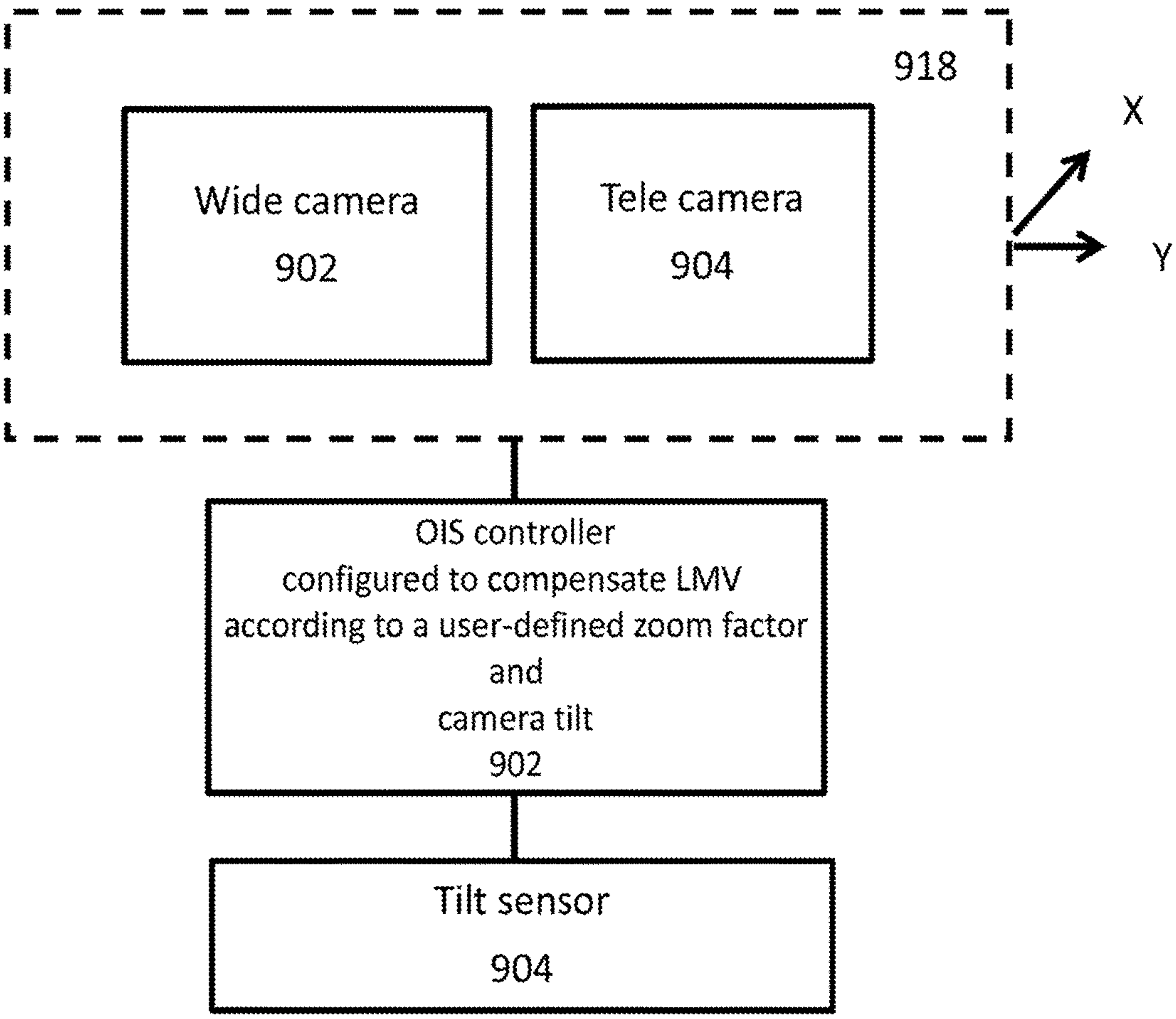

918
Wide camera
902
Tele camera
904
X
Y
OIS controller
configured to compensate LMV
according to a user-defined zoom factor
and
camera tilt
902
Tilt sensor
904

FIG. 9

MINIATURE TELEPHOTO LENS MODULE AND A CAMERA UTILIZING SUCH A LENS MODULE

TECHNOLOGICAL FIELD

The present invention is generally in the field of imaging techniques, and relates to a camera and mobile electronic devices utilizing such a camera.

BACKGROUND

Digital camera modules are currently being incorporated into a variety of portable electronic devices. Such devices include for example mobile phones (e.g. smartphones), personal data assistants (PDAs), computers, and so forth. Digital camera modules for use in portable devices have to meet certain requirements such as good quality imaging, small footprint, as well as low weight.

Several techniques for small digital camera modules providing good quality imaging are described in WO14083489 and WO14199338, both assigned to the assignee of the present application.

According to the technique described in WO14083489, a multi-aperture imaging system comprises a first camera with a first sensor that captures a first image and a second camera with a second sensor that captures a second image. The two cameras have either identical or different FOVs. Either image may be chosen to be a primary or an auxiliary image, based on a zoom factor. An output image with a point of view determined by the primary image is obtained by registering the auxiliary image to the primary image.

The technique described in WO14199338 relates to a dual-aperture zoom digital camera operable in both still and video modes. The camera includes Wide and Tele imaging sections with respective lens/sensor combinations and image signal processors and a camera controller operatively coupled to the Wide and Tele imaging sections. The controller is configured to combine in still mode at least some of the Wide and Tele image data to provide a fused output image from a particular point of view, and to provide, without fusion, continuous zoom video mode output images, each output image having a given output resolution. The video mode output images are provided with a smooth transition when switching between a lower zoom factor (ZF) value and a higher ZF value or vice versa. At the lower ZF the output resolution is determined by the Wide sensor, while at the higher ZF value the output resolution is determined by the Tele sensor.

General Description

There is a need in the art for a novel camera module for use in modern portable electronic devices, such as smart phones, laptops, notepads, etc.

As noted above, the requirements for the camera modules for use in such devices are related to the size, weight and image quality of the camera. Moreover, these requirements become more essential when the camera module is to be installed within the portable device, unlike other external camera units attachable to the portable device. In the case of an internal (integral) camera unit, the dimensions of the camera optics should be as small as possible in order to be suitable to operate with commonly used detectors and to fit the thickness of the device in which the camera is installed (preferably without protruding from the device's casing), while the trend in such devices is to reduce the thickness as much as possible.

This problem is even more crucial when using, in a portable device, a lens with a long length with a fixed and relatively high zooming effect. Considering for example the dual-aperture zoom digital camera described in above-indicated publications WO014083489 and WO014199338 mentioned above, it utilizes Wide and Tele imaging channels which provide advanced imaging capabilities such as zoom and image quality by image fusion between the two channels.

One of the problems with dual-aperture zoom cameras relates to the dimensions (heights) of Wide and Tele cameras along the optical axis. Such dimensions depend on total track lengths (TTLs) of the Tele and Wide lenses used in the respective imaging channels.

As schematically illustrated in FIG. **1**B, the TTL is typically defined as the maximal distance between the object-side surface of the lens module and an image plane IP defined by such a lens module (where the sensing surface of a camera detector is placed). In most miniature lenses, the TTL is larger than the effective focal length (EFL) of the lens module, which is equal to the distance between the effective principal plane of the lens and its focal plane (which substantially coincides with image plane IP).

With regard to the term effective principal plane, the following should be understood. Generally, the lens (or lens module) has front and rear principal planes, which have the property that a ray emerging from the lens appears to have crossed the rear principal plane at the same distance from the axis that that ray appeared to cross the front principal plane, as viewed from the front of the lens. This means that the lens can be treated as if all of the refraction occurred at the principal planes. The principal planes are crucial in defining the optical properties of the system, since it is the distance of the object and image from the front and rear principal planes that determine the magnification of the system. The principal points are the points where the principal planes cross the optical axis.

Considering dual-aperture optical zoom in a mobile phone (e.g. a smartphone) with the typically used lenses, i.e. typical TTL/EFL ratio of about 1.3, the Wide and Tele lenses would have TTLs of about 4.55 mm and 9.1 mm, respectively. This will result in undesirably long camera modules for use in such a smartphone device.

Further, the difference in the TTLs of the Wide and Tele lens modules can cause shadowing and light-blocking problems. Reference is made to FIG. **1**A schematically illustrating that part of incoming light incident on the "higher" lens does not reach the "shorter" lens. In this connection, one should keep in mind that a distance between the Tele and Wide lens modules should be as small as possible to meet the overlapping/common FOVs as well as footprint requirements for the camera unit in a portable device.

Another part of the presently disclosed subject matter is associated with the implementation of standard optical image stabilization (OIS) in a dual-aperture zoom camera. Standard OIS compensates for camera tilt ("CT") by a parallel-to-the image sensor (exemplarily in the X-Y plane) lens movement ("LMV"). Camera tilt causes image blur. The amount of LMV (in mm) needed to counter a given camera tilt depends on the cameras lens EFL, according to the relation LMV=CT*EFL where "CT" is in radians and EFL is in mm. Since, as shown above, a dual-aperture zoom camera may include two lenses with significantly different EFLs, it is impossible to move both lenses together and achieve optimal tilt compensation for both Tele and Wide cameras. That is, since the tilt is the same for both cameras, a movement that will cancel the tilt for the Wide camera will

be insufficient to cancel the tilt for the Tele camera. Similarly, a movement that will cancel the tilt for the Tele camera will over-compensate the tilt cancellation for the Wide camera. Assigning a separate OIS actuator to each camera can achieve simultaneous tilt compensation, but at the expense of a complicated and costly camera system.

Thus, for both a single-aperture or multi-aperture (dual) camera unit, the use of a telephoto lens would be advantageous, as such a telephoto lens provides reduced TTL while enabling to maintain the relatively high EFL required for the Tele lens, i.e. for telephoto lens TTL<EFL. However, the dimensions of conventional lenses in which the telephoto condition is satisfied do not allow them to be used as integral lenses fully embedded in a thin portable device. The telephoto lens module, in order to be used as an integral lens in a modern portable device, has to satisfy the telephoto condition (i.e. TTL<EFL) while the lens module is to be as short as possible (along the optical path of light passing through it) allowing it to be fully fitted within the portable device casing.

Accordingly, a miniature telephoto lens module is disclosed which is designed with the desired dimensions to enable its integration within a portable device. According to some examples of the presently disclosed subject matter, the miniature telephoto lens module (or telephoto lens unit) is designed to be completely integrated within the casing of a conventional Smartphone, i.e. without protruding therefrom. The disclosed telephoto lens module has a total track lens (TTL) smaller than an effective focal lens (EFL) thereof, and is configured such that its dimension along the optical axis is desirably small, i.e. about 4-15 mm or less (e.g. suitable to be fitted in a portable device having a casing as small as 4 mm).

The telephoto lens unit comprises multiple lens elements made of at least two different polymer materials having different Abbe numbers. The multiple lens elements comprise a first group of at least three lens elements being a telephoto lens assembly, and a second group of at least two lens elements being a field lens assembly.

The first group of lens elements comprises, in order from the object plane to the image plane along an optical axis of the telephoto lens unit: a first lens having positive optical power and a pair of second and third lenses having together negative optical power such that said telephoto lens assembly provides a telephoto optical effect of said telephoto lens unit and wherein said second and third lenses are each made of one of said at least two different polymer materials having a different Abbe number, for reducing chromatic aberrations of said telephoto lens. The second group of lens elements is configured to correct field curvature of said telephoto lens assembly, and said field lens module comprises two or more of said lens elements made of the different polymer materials respectively having different Abbe numbers, and configured to compensate for residual chromatic aberrations of said telephoto lens assembly dispersed during light passage through an effective gap located between the telephoto and field lens assemblies. The effective gap is larger than ⅕ of the TTL of the telephoto lens unit, thereby allowing sufficient field separation for reducing chromatic aberration.

Various examples disclosed herein include an optical lens unit comprising, in order from an object side to an image side: a first lens element with positive refractive power having a convex object-side surface, a second lens element with negative refractive power having a thickness d_2 on an optical axis and separated from the first lens element by a first air gap, a third lens element with negative refractive power and separated from the second lens element by a

second air gap, a fourth lens element having a positive refractive power and separated from the third lens element by an effective third air gap, and a fifth lens element having negative refractive power, separated from the fourth lens element by an effective fourth air gap, the fifth lens element having a thickness d_5 on the optical axis.

An optical lens unit may further include a stop, positioned before the first lens element, a glass window disposed between the image-side surface of the fifth lens element and an image sensor with an image plane on which an image of the object is formed.

Each lens element has two surfaces, each surface having a respective diameter. The largest diameter among all lens elements is defined as an "optical diameter" of the lens assembly.

As disclosed herein, TTL is defined as the distance on an optical axis between the object-side surface of the first lens element and an image plane where the image sensor is placed. "EFL" has its regular meaning, as mentioned above. In all embodiments, TTL is smaller than the EFL, i.e. the TTL/EFL ratio is smaller than 1.0. In some embodiments, the TTL/EFL ratio is smaller than 0.9. In an embodiment, the TTL/EFL ratio is about 0.85. According to some examples the lens assembly has an F number F#<3.2.

According to an example disclosed herein, the focal length of the first lens element f**1** is smaller than TTL/2, the first, third and fifth lens elements have each an Abbe number ("Vd") greater than 50, the second and fourth lens elements have each an Abbe number smaller than 30, the first air gap is smaller than $d_2/2$, the effective third air gap is greater than TTL/5 and the effective fourth air gap is smaller than $1.5d_5$TTL/50. In some embodiments, the surfaces of the lens elements may be aspheric.

In the optical lens unit mentioned above, the first lens element with positive refractive power allows the TTL of the lens unit to be favorably reduced. The combined design of the first, second and third lens elements plus the relative short distances between them enable a long EFL and a short TTL. The same combination, together with the high dispersion (low Vd) for the second lens element and low dispersion (high Vd) for the first and third lens elements, also helps to reduce chromatic aberration. In particular, the ratio TTL/EFL<1.0 and minimal chromatic aberration are obtained by fulfilling the relationship $1.2\times|f3|>|f2|>1.5\times f1$, where "f" indicates the lens element effective focal length and the numerals 1, 2, 3, 4, 5 indicate the lens element number.

The relatively large effective gap between the third and the fourth lens elements plus the combined design of the fourth and fifth lens elements assist in bringing all fields' focal points to the image plane. Also, because the fourth and fifth lens elements have different dispersions and have respectively positive and negative power, they help in minimizing chromatic aberration.

The telephoto lens module disclosed herein may be advantageously adapted to be incorporated in a mobile phone camera that uses a typical ¼' or ⅓' image sensor. For example, to be competitive with known mobile phone cameras with ¼' image sensors, it would be advantageous for the TTL of the telephoto lens module to be smaller than 5.5 mm and the largest lens diameter to be smaller than 4 mm. To be competitive with known mobile phone cameras with ⅓' image sensors, it would be advantageous for the TTL of the telephoto lens module to be smaller than 6.5 mm and the largest lens diameter to be smaller than 5 mm.

Accordingly to an example of the presently disclosed subject matter there is provided an optical lens unit configured to provide an image on an entire area of a ¼" image

sensor, the lens unit comprising five lens elements and having a TTL smaller than 5.5 mm, an EFL larger than 5.9 mm, and an optical diameter smaller than 4 mm.

Accordingly in another example of the presently disclosed subject matter there is provided an optical lens unit operative to provide an image on an entire area of a ⅓" image sensor, the lens unit comprising five lens elements and having a TTL smaller than 6.2 mm, an EFL larger than 6.8 mm, and an optical diameter smaller than 5 mm.

Also, as mentioned above, according to the presently disclosed subject matter it is suggested to have all lens elements made of polymer material such as plastic. While lenses made of polymer material are advantageous for reducing the price tag of the telephoto lens module as well as its weight, there are very few polymer materials which are suitable for this purpose. This is different to glass lenses which can be made of a variety of different glass materials, each characterized by a different Abbe number. The scarcity in polymer materials presents a challenge when designing lenses for a telephoto lens module. This challenge is at least partly due to the limitation in possible combinations of different lenses with different Abbe numbers which can be used for the purpose of correcting field curvature and compensating for chromatic aberrations.

Thus, according to one aspect of the presently disclosed subject matter there is provided a mobile electronic device comprising an integrated camera, wherein the camera comprises a Wide camera unit comprising a Wide lens unit, and a Telephoto camera unit comprising a telephoto lens unit, the telephoto lens unit and the wide lens unit having respectively TTL/EFL ratios smaller and larger than 1 and defining separate telephoto and wide optical paths.

In addition to the above features, the mobile electronic device according to this aspect of the presently disclosed subject matter can optionally comprise one or more of features (i) to (xvi) below, in any desired combination or permutation:

(i). wherein light receiving outer surfaces of the Wide and Telephoto lens units are located substantially in the same plane, thereby reducing shadowing and light blocking effects therebetween.

(ii). wherein the Wide and Telephoto camera units are mounted on separate printed circuit boards.

(iii). wherein the printed circuit boards are located in different spaced-apart substantially parallel planes.

(iv). wherein the Wide and Telephoto camera units are mounted directly on a single printed circuit board.

(v). wherein the Wide and Telephoto camera units are spaced from one another a distance d of about 1 mm.

(vi). wherein the telephoto lens unit is made of at least two polymer materials.

(vii). wherein the telephoto lens has a total track lens (TTL) not exceeding 15 mm.

(viii). wherein the telephoto lens has TTL less than 10 mm.

(ix). wherein the telephoto lens unit comprises multiple lens elements made of at least two different polymer materials having different Abbe numbers, the multiple lens elements comprise a first group of at least three lens elements configured to form a telephoto lens assembly, and a second group of at least two lens elements configured to form a field lens assembly, wherein the field lens assembly is spaced from the telephoto lens assembly by a predetermined effective gap.

(x). wherein said at least two different polymer materials comprise at least one plastic material with the Abbe number larger than 50, and at least one plastic material with the Abbe number smaller than 30.

(xi). wherein the first group of lens elements comprises, in order from an object plane to an image plane along an optical axis of the telephoto lens unit: a first lens having positive optical power and a pair of second and third lenses having together negative optical power such that said telephoto lens assembly provides telephoto optical effect of said telephoto lens unit, and said second and third lenses are each made of one of said at least two different polymer materials having a different Abbe number, for reducing chromatic aberrations of said telephoto lens; and

the second group of lens elements is configured to correct field curvature of said telephoto lens assembly, and comprises two or more of said lens elements made of the different polymer materials respectively having different Abbe numbers, and configured to compensate for residual chromatic aberrations of said telephoto lens assembly dispersed during light passage through said effective gap between the telephoto and field lens assemblies.

(xii). wherein the first, third and fifth lens elements have each an Abbe number greater than 50, and the second and fourth lens elements have each an Abbe number smaller than 30.

(xiii). wherein the predetermined effective gap is equal to or larger than ⅕ of the TTL of the telephoto lens unit.

(xiv). wherein the lens elements of the field lens assembly are spaced from one another an effective air gap smaller than 1/50 of the TTL of the telephoto lens unit.

(xv). wherein the telephoto lens unit has a TTL smaller than 5.5 mm, an effective focal length (EFL) larger than 5.9 mm, and an optical diameter smaller than 4 mm, thereby enabling to provide an image on an entire area of a ¼" image sensor.

(xvi). wherein the telephoto lens unit has a TTL smaller than 6.2 mm, an effective focal length (EFL) larger than 6.8 mm, and an optical diameter smaller than 5 mm, thereby enabling to provide an image on an entire area of a ⅓" image sensor.

According to another aspect of the presently disclosed subject matter there is provided a camera for integrating in a mobile electronic device, the camera comprising a Wide camera unit and a Telephoto camera unit comprising respectively a wide lens unit and a telephoto lens unit having TTL/EFL ratios larger and smaller than 1, respectively, and defining wide and telephoto optical paths.

Wherein according to some examples the lens elements of at least the telephoto lens unit are made of one or more polymer materials.

BRIEF DESCRIPTION OF THE DRAWINGS

In order to better understand the subject matter that is disclosed herein and to exemplify how it may be carried out in practice, embodiments will now be described, by way of non-limiting example only, with reference to the accompanying drawings, in which:

FIG. **1**A is a schematic illustration demonstrating shadowing and light-blocking problems caused by height differences between Wide and Tele cameras in a dual-aperture camera;

FIG. **1**B is a schematic illustration of a mobile phone device (constituting a portable electronic device) utilizing a camera unit as disclosed herein which is fully integrated inside the smartphone device;

FIG. 1C is a schematic illustration of a telephoto lens unit according to the presently disclosed subject matter;

FIG. 2A is a schematic illustration of a specific configuration of the telephoto lens unit, according to a first example of the presently disclosed subject matter;

FIG. 2B shows a graph plotting the modulus of the optical transfer function (MTF) vs. focus shift of the entire optical lens unit of FIG. 2A for various fields;

FIG. 2C shows a graph plotting the distortion vs. field angle (+Y direction) for the lens unit of FIG. 2A;

FIG. 3A is a schematic illustration of another possible configuration of the telephoto lens unit, according to a first example of the presently disclosed subject matter;

FIG. 3B shows a graph plotting the MTF vs. focus shift of the entire optical lens assembly for various fields in the lens unit of FIG. 3B, according to the second example of the presently disclosed subject matter;

FIG. 3C shows a graph plotting the distortion +Y in percent for the lens unit of FIG. 3A;

FIG. 4A is a schematic illustration of a specific configuration of the telephoto lens unit, according to a first example of the presently disclosed subject matter;

FIG. 4B shows a graph plotting the MTF vs. focus shift of the entire optical lens system for various fields in the lens unit of FIG. 4A;

FIG. 4C shows a graph plotting the distortion +Y in percent for the lens unit of FIG. 4A;

FIG. 5 is a schematic illustration showing the concept of an effective air gap between adjacent lenses in an optical lens unit, according to the presently disclosed subject matter;

FIG. 6A is a schematic illustration, in perspective cross section, of an example of a dual-aperture zoom camera, with each camera on a separate printed circuit board (PCB), according to the presently disclosed subject matter;

FIG. 6B is a schematic illustration, in perspective cross section, of another example of a dual-aperture zoom camera, with each camera on a separate PCB, according to the presently disclosed subject matter;

FIG. 7 is a schematic illustration, in perspective cross section, of yet another example of a dual-aperture zoom camera, where both cameras are mounted on a single PCB, according to the presently disclosed subject matter;

FIG. 8 is a schematic illustration of an example of a dual-aperture zoom camera that includes an OIS mechanism, according to the presently disclosed subject matter; and

FIG. 9 shows schematically a functional block diagram of the camera example of FIG. 8, according to the presently disclosed subject matter.

DETAILED DESCRIPTION OF EMBODIMENTS

The present invention includes novel configuration of a lens unit in a portable camera, advantageously applicable in a portable electronic device. This is schematically illustrated in FIG. 1B. In this example, such a portable electronic device 10 is constituted by a mobile phone device (e.g. smartphone). The mobile device is typically a few millimeters thick, e.g. 4 mm-15 mm.

However, as explained above and exemplified further below, the problems solved by the technique disclosed herein are relevant for any modern electronic device equipped with a camera 15 and suitable to be implemented in any such device. This is so since any modern electronic device of the kind specified (i.e. a device including an integral camera unit) is to be as slim as possible, as light as possible, and is to acquire pictures with as good quality as possible.

Modern cameras typically require zooming functions. When such a camera is used in an electronic device, such as a mobile phone device, the zooming function is often implemented with static optics. The problems which may arise when trying to incorporate Wide and Tele lenses into a common housing due to the difference in their heights are described above with reference to FIG. 1A.

As mentioned above, the presently disclosed subject matter includes a novel mobile electronic device 10 which includes an integrated camera unit 15 which is mounted inside the device casing 14. The camera 15 includes at least one telephoto lens unit (not shown here) which is made of polymer materials. The telephoto lens unit is configured such that its total track lens (TTL) is less than 15 mm and even less than 10 mm, e.g. less than 6 mm or even less than 4 mm. Thus, enabling the camera to be fully integrated in the portable device (substantially not protruding from the device casing).

Reference is made to FIG. 1C showing schematically the configuration of a telephoto lens unit 20 of the present invention. The telephoto lens unit 20 is composed of multiple lens elements made of different polymer materials, i.e. materials having different Abbe numbers. The multiple lens elements are configured and arranged to define a telephoto lens assembly 22A and a field lens assembly 22B arranged along an optical axis OA with a predetermined effective gap G between them (as will be described more specifically further below). The telephoto lens assembly 22A is configured to provide the telephoto optical effect of the telephoto lens unit 20. The field lens assembly 22B spaced from the telephoto lens assembly 22A by the predetermined effective gap G is configured for correcting field curvature of the telephoto lens assembly 22A and to compensate for residual chromatic aberrations of the telephoto lens assembly dispersed during light passage through the effective gap G.

The telephoto lens unit 20 is characterized by a total track lens (TTL) and an effective focal lens (EFL) such that TTL<EFL. This will be exemplified further below. According to the invention, the effective gap G between assemblies 22A and 22B is selected to be larger than TTL/5 of the telephoto lens unit 22A, thereby enabling correction of field curvature of telephoto lens assembly 22A by the field lens assembly 22B.

The telephoto lens assembly 22A includes three lens elements (generally three or more) L1, L2, L3 (which are shown here schematically and not to scale), where lens L1 has positive optical power and lenses L2 and L3 have together negative optical power. Lenses L2 and L3 are made of the first polymer material having a first Abbe number selected for reducing chromatic aberrations of the telephoto lens assembly 22A. The field lens assembly 22B includes two (or more) lens elements L4 and L5 which are made of different polymer materials respectively having different Abbe numbers. These lenses are configured to compensate for residual chromatic aberrations of the telephoto lens assembly 22A dispersed during light passage through the effective gap G between the 22A and 22B.

Lenses L1-L5 can be made for example of two plastic materials, one having an Abbe number greater than 50 and the other—smaller than 30. For example, Lenses L1, L3 and L5 are made of plastic with an Abbe number greater than 50, and lenses L2 and L4 are made of plastic having an Abbe number smaller than 30.

The following are several specific, but non-limiting, examples of the implementation and operation of the telephoto lens unit of the invention described above with reference to FIG. **1**C. In the following description, the shape (convex or concave) of a lens element surface is defined as viewed from the respective side (i.e. from an object side or from an image side).

FIG. **2**A shows a schematic illustration of an optical lens unit **100**, according to a first example of the presently disclosed subject matter. FIG. **2**B shows the MTF vs. focus shift of the entire optical lens unit for various fields in the lens unit configuration **100**. FIG. **2**C shows the distortion +Y in percent vs. field.

According to the example illustrated in FIG. **2**A, lens unit **100** includes, in order from an object side to an image side, a first plastic lens element **102** (also referred to as "L**1**") with positive refractive power having a convex object-side surface **102***a* and a convex or concave image-side surface **102***b*; a second plastic lens element **104** (also referred to as "L**2**") with negative refractive power and having a meniscus convex object-side surface **104***a*, with an image side surface marked **104***b*; a third plastic lens element **106** (also referred to as "L**3**") with negative refractive power having a concave object-side surface **106***a* with an inflection point and a concave image-side surface **106***b*. These lens elements define together the telephoto lens assembly (**22**A in FIG. **1**C). Further provided in lens unit **100** is a fourth plastic lens element **108** (also referred to as "L**4**") with positive refractive power having a positive meniscus, with a concave object-side surface marked **108***a* and an image-side surface marked **108***b*; and a fifth plastic lens element **110** (also referred to as "L**5**") with negative refractive power having a negative meniscus, with a concave object-side surface marked **110***a* and an image-side surface marked **110***b*. These two lenses define together the field lens assembly (**22**B in FIG. **1**C). The optical lens unit **100** may further optionally include a stop element **101**. The telephoto lens unit **100** defines an image plane **114** in which image sensor(s) is/are located, which is not shown here. Also, as exemplified in the figure, an optional glass window **112** is disposed between the image-side surface **110***b* of fifth lens element **110** and the image plane **114**.

In the example of the telephoto lens unit **100**, all lens element surfaces are aspheric. Detailed optical data is shown in Table 1, and aspheric surface data is shown in Table 2, wherein the units of the radius of curvature (R), lens element thickness and/or distances between elements along the optical axis and diameter are expressed in mm. "Nd" is the refraction index. The equation of the aspheric surface profiles is expressed by:

$$z = \frac{cr^2}{1+\sqrt{1-(1+k)c^2r^2}} + \alpha_1 r^2 + \alpha_2 r^4 + \alpha_3 r^6 + \alpha_4 r^8 + \alpha_5 r^{10} + \alpha_6 r^{12} + \alpha_7 r^{14}$$

where r is the distance from (and is perpendicular to) the optical axis, k is the conic coefficient, c=1/R where R is the radius of curvature, and α are coefficients given in Table 2.

In the equation above as applied to the telephoto lens unit, coefficients α_1 and α_7 are zero. It should be noted that the maximum value of r "max r"=Diameter/2. It should also be noted that in Table 1 (and in Tables 3 and 5 below), the distances between various elements (and/or surfaces) are marked "Lmn" (where m refers to the lens element number, n=1 refers to the element thickness and n=2 refers to the air gap to the next element) and are measured on the optical axis z, wherein the stop is at z=0. Each number is measured from the previous surface. Thus, the first distance—0.466 mm is measured from the stop to surface **102***a*, the distance L**11** from surface **102***a* to surface **102***b* (i.e. the thickness of first lens element **102**) is 0.894 mm, the air gap L**12** between surfaces **102***b* and **104***a* is 0.020 mm, the distance L**21** between surfaces **104***a* and **104***b* (i.e. thickness d**2** of second lens element **104**) is 0.246 mm, etc. Also, L**21**=d_2 and L**51**=d_5. The lens elements in Tables 1 and 2 (as well as in Tables 3-6) are designed to provide an image on an entire ⅓" sensor having dimensions of approximately 4.7×3.52 mm. The optical diameter in all of these lens assemblies is the diameter of the second surface of the fifth lens element.

TABLE 1

#	Comment	Radius R [mm]	Distances [mm]	Nd/Vd	Diameter [mm]
1	Stop	Infinite	−0.466		2.4
2	L11	1.5800	0.894	1.5345/57.095	2.5
3	L12	−11.2003	0.020		2.4
4	L21	33.8670	0.246	1.63549/23.91	2.2
5	L22	3.2281	0.449		1.9
6	L31	−12.2843	0.290	1.5345/57.095	1.9
7	L32	7.7138	2.020		1.8
8	L41	−2.3755	0.597	1.63549/23.91	3.3
9	L42	−1.8801	0.068		3.6
10	L51	−1.8100	0.293	1.5345/57.095	3.9
11	L52	−5.2768	0.617		4.3
12	Window	Infinite	0.210	1.5168/64.17	3.0
13		Infinite	0.200		3.0

TABLE 2

#	Conic coefficient k	α_2	α_3	α_4	α_5	α_6
2	−0.4668	7.9218E−03	2.3146E−02	−3.3436E−02	2.3650E−02	−9.2437E−03
3	−9.8525	2.0102E−02	2.0647E−04	7.4394E−03	−1.7529E−02	4.5206E−03
4	10.7569	−1.9248E−03	8.6003E−02	1.1676E−02	−4.0607E−02	1.3545E−02
5	1.4395	5.1029E−03	2.4578E−01	−1.7734E−01	2.9848E−01	−1.3320E−01
6	0.0000	2.1629E−01	4.0134E−02	1.3615E−02	2.5914E−03	−1.2292E−02
7	−9.8953	2.3297E−01	8.2917E−02	−1.2725E−01	1.5691E−01	−5.9624E−02
8	0.9938	−1.3522E−02	−7.0395E−03	1.4569E−02	−1.5336E−02	4.3707E−03
9	−6.8097	−1.0654E−01	1.2933E−02	2.9548E−04	−1.8317E−03	5.0111E−04
10	−7.3161	−1.8636E−01	8.3105E−02	−1.8632E−02	2.4012E−03	−1.2816E−04
11	0.0000	−1.1927E−01	7.0245E−02	−2.0735E−02	2.6418E−03	−1.1576E−04

Lens unit **100** provides a field of view (FOV) of 44 degrees, with EFL=6.90 mm, F#=2.80 and TTL of 5.904 mm. Thus and advantageously, the ratio TTL/EFL=0.855. Advantageously, the Abbe number of the first, third and fifth lens element is 57.095. Advantageously, the first air gap between lens elements **102** and **104** (the gap between surfaces **102***b* and **104***a*) has a thickness (0.020 mm) which is less than a tenth of thickness d_2 (0.246 mm). Advantageously, the Abbe number of the second and fourth lens elements is 23.91. Advantageously, an effective third air gap G (see below with reference to Table 9) between lens elements **106** and **108** (i.e. the telephoto and field lens assemblies) is greater than TTL/5. Advantageously, an effective fourth air gap (see below with reference to Table 9) between lens elements **108** and **110** is smaller than TTL/50.

The focal length (in mm) of each lens element in lens unit **100** is as follows: f**1**=2.645, f**2**=−5.578, f**3**=−8.784, f**4**=9.550 and f**5**=−5.290. The condition 1.2×|f**3**|>|f**2**|>1.5×f**1** is clearly satisfied, as 1.2×8.787>5.578>1.5×2.645. f**1** also fulfills the condition f**1**<TTL/2, as 2.645<2.952.

FIG. **3**A shows a schematic illustration of an optical lens unit **200**, according to another example of the presently disclosed subject matter. FIG. **3**B shows the MTF vs. focus shift of the entire optical lens system for various fields in embodiment **200**. FIG. **3**C shows the distortion +Y in percent vs. field.

According to the example illustrated in FIG. **3**A, lens unit **200** comprises, in order from an object side to an image side: an optional stop **201**; a telephoto lens assembly including a first plastic lens element **202** with positive refractive power having a convex object-side surface **202***a* and a convex or concave image-side surface **202***b*, a second plastic lens element **204** with negative refractive power, having a meniscus convex object-side surface **204***a*, with an image side surface marked **204***b*, and a third plastic lens element **206** with negative refractive power having a concave object-side surface **206***a* with an inflection point and a concave image-side surface **206***b*; and a field lens assembly including a fourth plastic lens element **208** with positive refractive power having a positive meniscus, with a concave object-side surface marked **208***a* and an image-side surface marked **208***b*, and a fifth plastic lens element **210** with negative refractive power having a negative meniscus, with a concave object-side surface marked **110***a* and an image-side surface marked **210***b*. The optical lens unit **200** further optionally includes a glass window **212** disposed between the image-side surface **210***b* of fifth lens element **210** and an image plane **214**.

In the lens unit **200**, all lens element surfaces are aspheric. Detailed optical data is given in Table 3, and the aspheric surface data is given in Table 4, wherein the markings and units are the same as in, respectively, Tables 1 and 2. The equation of the aspheric surface profiles is the same as for lens unit **100** described above.

TABLE 3

#	Comment	Radius R [mm]	Distances [mm]	Nd/Vd	Diameter [mm]
1	Stop	Infinite	−0.592		2.5
2	L11	1.5457	0.898	1.53463/56.18	2.6
3	L12	−127.7249	0.129		2.6
4	L21	6.6065	0.251	1.91266/20.65	2.1
5	L22	2.8090	0.443		1.8
6	L31	9.6183	0.293	1.53463/56.18	1.8
7	L32	3.4694	1.766		1.7
8	L41	−2.6432	0.696	1.632445/23.35	3.2
9	L42	−1.8663	0.106		3.6
10	L51	−1.4933	0.330	1.53463/56.18	3.9
11	L52	−4.1588	0.649		4.3
12	Window	Infinite	0.210	1.5168/64.17	5.4
13		Infinite	0.130		5.5

TABLE 4

#	Conic coefficient k	α_2	α_3	α_4	α_5	α_6
2	0.0000	−2.7367E−03	2.8779E−04	−4.3661E−03	3.0069E−03	−1.2282E−03
3	−10.0119	4.0790E−02	−1.8379E−02	2.2562E−02	−1.7706E−02	4.9640E−03
4	10.0220	4.6151E−02	5.8320E−02	−2.0919E−02	−1.2846E−02	8.8283E−03
5	7.2902	3.6028E−02	1.1436E−01	−1.9022E−02	4.7992E−03	−3.4079E−03
6	0.0000	1.6639E−01	5.6754E−02	−1.2238E−02	−1.8648E−02	1.9292E−02
7	8.1261	1.5353E−01	8.1427E−02	−1.5773E−01	1.5303E−01	−4.6064E−02
8	0.0000	−3.2628E−02	1.9535E−02	−1.6716E−02	−2.0132E−03	2.0112E−03
9	0.0000	1.5173E−02	−1.2252E−02	3.3611E−03	−2.5303E−03	8.4038E−04
10	−4.7688	−1.4736E−01	7.6335E−02	−2.5539E−02	5.5897E−03	−5.0290E−04
11	0.00E+00	−8.3741E−02	4.2660E−02	−8.4866E−03	1.2183E−04	7.2785E−05

Lens unit **200** provides a FOV of 43.48 degrees, with EFL=7 mm, F#=2.86 and TTL=5.90 mm. Thus, advantageously, the ratio TTL/EFL=0.843. Advantageously, the Abbe number of the first, third and fifth lens elements is 56.18. The first air gap between lens elements **202** and **204** has a thickness (0.129 mm) which is about half the thickness d_2 (0.251 mm). Advantageously, the Abbe number of the second lens element is 20.65 and of the fourth lens element is 23.35. Advantageously, the effective third air gap G between lens elements **206** and **208** is greater than TTL/5. Advantageously, the effective fourth air gap between lens elements **208** and **210** is smaller than TTL/50.

The focal length (in mm) of each lens element in lens unit **200** is as follows: f**1**=2.851, f**2**=−5.468, f**3**=−10.279, f**4**=7.368 and f**5**=−4.536. The condition 1.2×|f**3**|>|f**2**|>1.5×f**1** is clearly satisfied, as 1.2×10.279>5.468>1.5×2.851. f**1** also fulfills the condition f**1**<TTL/2, as 2.851<2.950.

FIG. **4**A shows a schematic illustration of an optical lens unit **300**, according to yet a further example of the presently

disclosed subject matter. FIG. **4**B shows the MTF vs. focus shift of the entire optical lens system for various fields in embodiment **300**. FIG. **4**C shows the distortion +Y in percent vs. field.

Lens unit **300** comprises, in order from an object side to an image side, an optional stop **301**; a telephoto lens assembly including a first plastic lens element **302** with positive refractive power having a convex object-side surface **302***a* and a convex or concave image-side surface **302***b*, a second plastic lens element **204** with negative refractive power, having a meniscus convex object-side surface **304***a*, with an image side surface marked **304***b*, a third plastic lens element **306** with negative refractive power having a concave object-side surface **306***a* with an inflection point and a concave image-side surface **306***b*; and a field lens assembly including a fourth plastic lens element **308** with positive refractive power having a positive meniscus, with a concave object-side surface marked **308***a* and an image-side surface marked **308***b*, and a fifth plastic lens element **310** with negative refractive power having a negative meniscus, with a concave object-side surface marked **310***a* and an image-side surface marked **310***b*. Also, an optional glass window **312** may be disposed between the image-side surface **310***b* of fifth lens element **310** and an image plane **314**.

According to the present example of lens unit **300**, all lens element surfaces are aspheric. Detailed optical data is given in Table 5, and the aspheric surface data is given in Table 6, wherein the markings and units are the same as in, respectively, Tables 1 and 2. The equation of the aspheric surface profiles is the same as for lens units **100** and **200**.

TABLE 5

#	Comment	Radius R [mm]	Distances [mm]	Nd/Vd	Diameter [mm]
1	Stop	Infinite	−0.38		2.4
2	L11	1.5127	0.919	1.5148/63.1	2.5
3	L12	−13.3831	0.029		2.3
4	L21	8.4411	0.254	1.63549/23.91	2.1
5	L22	2.6181	0.426		1.8
6	L31	−17.9618	0.265	1.5345/57.09	1.8
7	L32	4.5841	1.998		1.7
8	L41	−2.8827	0.514	1.63549/23.91	3.4
9	L42	−1.9771	0.121		3.7
10	L51	−1.8665	0.431	1.5345/57.09	4.0
11	L52	−6.3670	0.538		4.4
12	Window	Infinite	0.210	1.5168/64.17	3.0
13		Infinite	0.200		3.0

TABLE 6

#	Conic coefficient k	α_2	α_3	α_4	α_5	α_6
2	−0.534	1.3253E−02	2.3699E−02	−2.8501E−02	1.7853E−02	−4.0314E−03
3	−13.473	3.0077E−02	4.7972E−03	1.4475E−02	−1.8490E−02	4.3565E−03
4	−10.132	7.0372E−04	1.1328E−01	1.2346E−03	−4.2655E−02	8.8625E−03
5	5.180	−1.9210E−03	2.3799E−01	−8.8055E−02	2.1447E−01	−1.2702E−01
6	0.000	2.6780E−01	1.8129E−02	−1.7323E−02	3.7372E−02	−2.1356E−02
7	10.037	2.7660E−01	−1.0291E−02	−6.0955E−02	7.5235E−02	−1.6521E−02
8	1.703	2.6462E−02	−1.2633E−02	−4.7724E−04	−3.2762E−03	1.6551E−03
9	−1.456	5.7704E−03	−1.8826E−02	5.1593E−03	−2.9999E−03	8.0685E−04
10	−6.511	−2.1699E−01	1.3692E−01	−4.2629E−02	6.8371E−03	−4.1415E−04
11	0.000	−1.5120E−01	8.6614E−02	−2.3324E−02	2.7361E−03	−1.1236E−04

Lens unit **300** provides a FOV of 44 degrees, EFL=6.84 mm, F#=2.80 and TTL=5.904 mm. Thus, advantageously, the ratio TTL/EFL=0.863. Advantageously, the Abbe number of the first lens element is 63.1, and of the third and fifth lens elements is 57.09. The first air gap between lens elements **302** and **304** has a thickness (0.029 mm) which is about $1/10^{th}$ the thickness d_2 (0.254 mm). Advantageously, the Abbe number of the second and fourth lens elements is 23.91. Advantageously, the effective third air gap G between lens elements **306** and **308** is greater than TTL/5. Advantageously, the effective fourth air gap between lens elements **308** and **310** is smaller than TTL/50.

The focal length (in mm) of each lens element in embodiment **300** is as follows: f**1**=2.687, f**2**=−6.016, f**3**=−6.777, f**4**=8.026 and f**5**=−5.090. The condition 1.2×|f**3**|>|f**2**|>1.5×f**1** is clearly satisfied, as 1.2×6.777>6.016>1.5×2.687. f**1** also fulfills the condition f**1**<TTL/2, as 2.687<2.952.

Tables 7 and 8 provide respectively detailed optical data and aspheric surface data for a fourth embodiment of an optical lens system disclosed herein. The markings and units are the same as in, respectively, Tables 1 and 2. The equation of the aspheric surface profiles is the same as for lens systems **100**, **200** and **300**. The lens elements in Tables 7 and 8 are designed to provide an image on an entire ¼" sensor having dimensions of approximately 3.66×2.75 mm.

TABLE 7

#	Comment	Radius R [mm]	Distances [mm]	Nd/Vd	Diameter [mm]
1	Stop	Infinite	−0.427		2.1
2	L11	1.3860	0.847	1.534809/55.66	2.2
3	L12	−8.5270	0.073		2.1
4	L21	11.1443	0.239	1.639078/23.253	1.9
5	L22	1.8641	0.504		1.7
6	L31	19.7342	0.239	1.534809/55.66	1.7
7	L32	3.9787	1.298		1.7
8	L41	−3.3312	0.522	1.639078/23.253	2.8
9	L42	−1.7156	0.079		3.1
10	L51	−1.7788	0.298	1.534809/55.66	3.5
11	L52	−12.6104	0.792		3.7
12	Window	Infinite	0.210	1.5168/64.17	4.5
13		Infinite	0.177		4.6

TABLE 8

#	Conic coefficient k	α2	α3	α4	α5	α 6
2	−0.326	8.776E−03	2.987E−02	−6.001E−02	6.700E−02	−2.849E−02
3	−10.358	4.266E−02	−2.240E−02	2.914E−02	−3.025E−02	3.108E−03
4	11.447	−3.257E−02	9.780E−02	−1.143E−02	−3.844E−02	1.005E−02
5	−0.026	−3.631E−02	2.928E−01	−2.338E−01	3.334E−01	−2.760E−02
6	0.000	1.578E−01	−2.229E−02	−4.991E−02	1.663E−01	−1.298E−01
7	3.860	2.044E−01	5.451E−02	−3.199E−01	5.619E−01	−3.663E−01
8	4.094	3.706E−02	−5.931E−02	4.662E−02	−4.654E−02	1.606E−02
9	−9.119	−7.980E−02	−1.376E−03	5.622E−03	−6.715E−03	2.127E−03
10	−12.777	−2.695E−01	1.894E−01	−5.690E−02	8.689E−03	−5.269E−04
11	0.000	−1.807E−01	1.278E−01	−4.504E−02	6.593E−03	−2.357E−04

The focal length (in mm) of each lens element according to this example is as follows: f**1**=2.298, f**2**=−3.503, f**3**=−9.368, f**4**=4.846 and f**5**=−3.910. The condition 1.2×|f**3**|>|f**2**|>1.5×f**1** is clearly satisfied, as 1.2×9.368>3.503>1.5×2.298. f**1** also fulfills the condition f**1**<TTL/2, as 2.298<2.64.

Generally, with regard to the effective air gap between the adjacent lens elements, the following should be noted.

In each one of the lens units exemplified above, the first three lens elements (L**1**, L**2** and L**3**) achieve essentially a telephoto effect for all fields (angles of object orientation relative to the optical axis), i.e. achieve a strong concentration (by L**1**) followed by partial collimation (mainly by L**2** but also by L**3**). The fact that all fields need to have essentially the same telephoto effect leads to relatively small distances (small air gaps) between the three lens elements, e.g. especially between L**1** and L**2** (air gap **1**). L**4** and L**5** are mainly field lens elements for reducing field curvature, i.e. their main effect is to cause the focal point for all fields (where the object distance is approximately infinity) to reside on the sensor plane. To achieve this, it is advantageous that for every field, the corresponding rays hit L**4** and L**5** at different locations, thus enabling separate adjustment for every field ("field separation").

The inventors have found that the desired fields' separation is obtainable in a lens unit design characterized by an "effective air gap" G between lenses L**3** and L**4** (between the telephoto and field lens assemblies, where a larger G leads to larger separation between the fields).

FIG. **5** illustrates the concept of the effective air gap between the two adjacent lens elements. First, an "air gap per field" D_{f-n} is defined as the length of the nth field's chief ray along the respective chief ray between adjacent lens elements. Effective gap D_{Leff} is then defined as the average of N air gaps per field for field angles α separated evenly between α=0 (for ray **1**, air gap D_{f-1}) to $\alpha=\alpha_{max}$ (for ray N, air gap D_{f-n}), where ray N hits the end pixel on the image sensor diagonal. In other words, between each pair of adjacent lens elements (e.g. between L**3** and L**4** and between L**4** and L**5**):

$$D_{Leff}=(\Sigma_{n=1}^{N} D_{f-n})/N$$

In essence, the effective air gap between adjacent lens elements reflects an average effective distance between the two surfaces bounding the air gap between the two adjacent lens elements. Exemplarily, in FIG. **5** there are N=9 chief rays (and 9 related field air gaps) and the chief rays are distributed angularly evenly between α=0 for ray **1** and α_{max} for ray **9**. At α_{max}, ray **9** hits the end pixel on the image sensor diagonal.

Table 9 shows data on TTL, D_{Leff-3}, D_{Leff-4}, and ratios between the TTL and the effective air gaps for each of lens units **100**, **200** and **300** above. D_{Leff-3} and D_{Leff-4} were calculated using 9 chief rays, as shown in FIG. **4**.

TABLE 9

Embodiment	TTL	D_{Leff-3} = G	D_{Leff-4}	D_{Leff-3}/TTL	D_{Leff-4}/TTL
100	5.903	1.880	0.086	0.319	0.015
200	5.901	1.719	0.071	0.291	0.012
300	5.904	1.925	0.094	0.326	0.016
400	5.279	1.263	0.080	0.246	0.015

Using D_{Leff-3}=G instead of the commonly used distance along the optical axis between L**3** and L**4** ensures better operation (for the purpose of reduction of field curvature) of lens elements L**4** and L**5** for all the fields. As seen in Table 9, good field separation may exemplarily be achieved if D_{Leff-3}=G>TTL/5.

A compact optical design requires that the diameter of L**5** be as small as possible while providing the required performance. Since the lens and camera footprint is determined by L**5** diameter, a small effective air gap, D_{Leff-4}, between lenses L**4** and L**5** is advantageous in that it allows a small diameter of lens L**5** without degrading the optical performance Effective air gap D_{Leff-4} is a better indicator of the L**5** diameter than the commonly used air gap along the optical axis between L**4** and L**5**. An adequately small L**5** diameter may exemplarily be achieved if the effective air gap between the field lenses L**4** and L**5** is D_{Leff-4}<TTL/50.

It should be noted that an effective air gap D_{Leff} can be calculated in principle using any combination of two or more chief rays (for example ray **1** and ray **9** in FIG. **4**). However, the "quality" of D_{Leff} calculation improves while considering an increased number of chief rays.

The miniature telephoto lens units described above with reference to FIGS. **1**C and **2** to **5** are designed with a TTL shorter than EFL. Accordingly, due to shorter TTL, such lens units have a smaller field of view, as compared to standard mobile phone lens units. Therefore, it would be particularly useful to use such a telephoto lens unit as a Tele sub-camera lens unit in a dual aperture zoom camera. Such a dual aperture zoom camera is described in the above-mentioned WO14199338 of the same assignee as the present application.

As mentioned above, a problem associated with the use of conventional Wide and Tele lens modules in a camera is associated with the different lengths/heights of the lenses which can cause shadowing and light blocking effects. According to the presently disclosed subject matter it is suggested to eliminate or at least significantly reduce these shadowing and light blocking effects by replacing the conventional Tele lens module by the miniature telephoto lens unit described above in the dual aperture camera.

Thus, according to the presently disclosed subject matter, the problem discussed above posed by a difference in the TTL/EFL ratios of the conventional Tele and Wide lenses may be solved through use of a standard lens for the Wide camera ($TTL_W/EFL_W>1.1$, typically 1.3) and of a special Telephoto lens design for the Tele camera ($TTL_T/EFL_T<1$, e.g. 0.87), where the telephoto lens unit is configured as described above, providing the miniature telephoto lens unit.

Using the above described miniature telephoto lens unit enables to reduce the TTL_T (according to one non-limiting example down to 7×0.87=6.09 mm) leading to a camera height of less than 7 mm (which is an acceptable height for a smartphone or any other mobile electronic device). The height difference between the telephoto lens unit and the Wide lens unit is also reduced to approximately 1.65 mm, thus reducing shadowing and light blocking problems.

According to some examples of a dual-aperture camera disclosed herein, the ratio "e"=EFL_T/EFL_T, is in the range 1.3-2.0. In some embodiments, the ratio $TTL_T/TTL_W<0.8e$. In some embodiments, TTL_T/TTL_W is in the range 1.0-1.25. According to some examples disclosed herein, EFL_W may be in the range 2.5-6 mm and EFL_T may be in the range 5-12 mm.

Referring now to the figures, FIG. **6**A shows schematically in perspective cross section an example of a dual-aperture zoom camera device **600**. Camera device **600** includes two camera unit **602** and **604**. It should be understood that the two camera units may be associated with common or separate detectors (pixel matrix and their associated read out circuits). Thus, the two camera units are actually different in their optics, i.e. in the imaging channels defined by the wide and telephoto lens units. Each camera unit may be mounted on a separate PCB (respectively **605***a* and **605***b*) including the read out circuit, and includes a lens unit (respectively **606** and **608**), and an image sensor including a pixel matrix (respectively **614** and **616**), and an actuator (respectively **610** and **612**) associated with a focusing mechanism. In this embodiment, the two PCBs lie in the same plane. It should be understood that in the embodiment where the readout circuits of the two imaging channels are in the same plane, a common PCB can be used, as will be described further below. The two camera units are connected by a case **618**. For example, camera **602** includes a Wide lens unit and camera **604** includes a Telephoto lens unit, the TTL_T of the lens unit defining the respective camera height H. For example, the Wide and Telephoto lens units provide respectively main and auxiliary optical/imaging paths, enabling to use the main image for interpreting the auxiliary image data.

FIG. **6**B shows schematically, in perspective cross, another example of a dual-aperture zoom camera **600'** utilizing the principles of the invention. Camera **600'** is generally similar to the above-described camera **600**, and the common components are shown in the figure in a self-explanatory manner and thus are not indicated by reference numbers. As in camera **600**, in the camera **600'**, the camera unit **602** (e.g. a Wide lens camera) and camera unit **604** (e.g. a Telephoto lens camera) are mounted on separate PCBs (respectively **605***a* and **605***b*). However, in contrast with camera **600**, in camera **600'** the two PCBs lie in different planes. This enables the object side principal planes of the Wide and Telephoto lens units to be close one to the other, thus reducing the dependency of magnification factor in the two units on the object distance.

For example, camera dimensions for the cameras shown in FIGS. **6**A and **6**B may be as follows: a length L of the camera (in the Y direction) may vary between 13-25 mm, a width W of the camera (in the X direction) may vary between 6-12 mm, and a height H of the camera (in the Z direction, perpendicular to the X-Y plane) may vary between 4-12 mm. More specifically, considering a smartphone camera example disclosed herein, L=18 mm, W=8.5 mm and H=7 mm.

FIG. **7** shows schematically, in perspective cross section, yet another example of a dual-aperture zoom camera **700**. Camera **700** is similar to cameras **600** and **600'** in that it includes two camera units **702** and **704** with respective lens units **706** and **708**, respective actuators **710** and **712** and respective image sensors **714** and **716**. However, in camera **700**, the two camera units **702** and **704** are mounted on a single (common) PCB **705**. The mounting on a single PCB and the minimizing of a distance "d" between the two camera units minimizes and may even completely avoid camera movement (e.g. associated with mishaps such as drop impact). In general, the dimensions of camera **700** may be in the same range as those of cameras **600** and **600'**. However, for the same sensors and optics, the footprint W×L and the weight of camera **700** are smaller than that of cameras **600** and **600'**. Mishaps such as drop impact may cause a relative movement between the two cameras after system calibration, changing the pixel matching between the Tele and Wide images and thus preventing fast reliable fusion of the Tele and Wide images. Therefore, such effects should preferably be eliminated.

As described above, the high-quality imaging is also associated with the implementation of standard optical image stabilization (OIS) in such a dual-aperture zoom camera. Standard OIS compensates for camera tilt ("CT"), i.e., image blur, by a parallel-to-the image sensor (exemplarily in the X-Y plane) lens movement ("LMV"). The amount of LMV (in millimeters) needed to counter a given camera tilt depends on the camera lens EFL, according to the relation:

$$LMV=CT*EFL,$$

where "CT" is in radians and EFL is in mm.

Since the Wide and telephoto lens units have significantly different EFLs, both lenses cannot move together and achieve optimal tilt compensation for both of the respective camera units. More specifically, since the tilt is the same for both camera units, a movement that will compensate for the tilt for the Wide camera unit will be insufficient to compensate for the tilt for the Telephoto camera unit, and vice versa. Using separate OIS actuators for the two camera units respectively can achieve simultaneous tilt compensation for both of them, but the entire system would be complex and costly, which is undesirable for portable electronic devices.

In this connection, reference is made to FIG. **8** which shows an example of a dual-aperture zoom camera **800** (similar to the above-described camera **700**) that includes two camera units **802** and **804** mounted either on a single PCB **805** (as shown in this example) or on separate PCBs. Each camera unit includes a lens unit (respectively **806** and **808**), an actuator (respectively **810** and **812**) and an image sensor (respectively **814** and **816**). The two actuators are rigidly mounted on a rigid base **818** that is flexibly connected to the PCB (or PCBs) through flexible elements **820**. Base **818** is movable by an OIS mechanism (not shown) controlled by an OIS controller **902** (shown in FIG. **9**). The OIS controller **902** is coupled to, and receives camera tilt information from a tilt sensor (e.g. a gyroscope) **904** (FIG. **9**). More details of an example of an OIS procedure as disclosed herein are given below with reference to FIG. **9**. The two camera units are separated by a small distance "d",

e.g. 1 mm. This small distance between camera units also reduces the perspective effect enabling smoother zoom transition between the camera units.

As indicated above, the two image sensors **814** and **816** may be mounted on separate PCBs that are rigidly connected, thereby enabling adaptation of an OIS mechanism to other system configurations, for example those described above with reference to FIGS. **6**A and **6**B.

In some embodiments, and optionally, a magnetic shield plate may be used, e.g. as described in co-owned U.S. patent application Ser. No. 14/365,718 titled "Magnetic shielding between voice coil motors in a dual-aperture camera", which is incorporated herein by reference in its entirety. Such a magnetic shield plate may be inserted in the gap (with width d) between the Wide and Tele camera units.

In general, the dimensions of camera **800** may be in the same range as those of cameras **600**, **600'** and **700**.

Reference is made to FIG. **9**, which exemplifies the camera operation, utilizing a tilt sensor **904** which dynamically measures the camera tilt (which is the same for both the Wide and Tele camera units). As shown, an OIS controller **902** (electronic circuit including hardware/software components) is provided, which is coupled to the actuators of both camera units (e.g. through base **818**), and receives a CT input from the tilt sensor **904** and a user-defined zoom factor, and controls the lens movement of the two camera units to compensate for the tilt. The LMV is for example in the X-Y plane. The OIS controller **902** is configured to provide a LMV equal to $CT*EFL_{ZF}$, where "EFL_{ZF}" is chosen according to the user-defined zoom factor, ZF. According to one example of an OIS procedure, when ZF=1, LMV is determined by the Wide camera unit's EFL_W (i.e. $EFL_{ZF}=EFL_W$ and $LMV=CT*EFL_W$). Further, when ZF>e (i.e. $ZF>EFL_T/EFL_W$), LMV is determined by the telephoto camera unit's EFL_T (i.e. $EFL_{ZF}=EFL_T$ and $LMV=CT*EFL_T$). Further yet, for a ZF between 1 and e, the EFL_{ZF} may shift gradually from EFL_W to EFL_T according to $EFL_{ZF}=ZF*EFL_W$.

Thus, the present invention provides a novel approach for configuring a camera device suitable for use in portable electronic devices, in particular smart phones. The present invention solves various problems associated with the requirements for physical parameters of such devices (weight, size), high image quality and zooming effects.

The invention claimed is:

1. A mobile electronic device comprising an integrated camera, wherein the camera comprises a Wide camera unit comprising a Wide lens unit and a Telephoto camera unit comprising a Telephoto lens unit, the Telephoto lens unit and the Wide lens unit having, respectively, total track length (TTL)/effective focal length (EFL) ratios smaller and larger than 1 and defining separate Telephoto and Wide optical paths, wherein the Telephoto lens unit comprises multiple lens elements made of at least two different polymer materials having different Abbe numbers, wherein the multiple lens elements comprise a first group of at least three lens elements configured to form a telephoto lens assembly and a second group of at least two lens elements, the second group of at least two lens elements spaced apart from the first group of at least three lens elements by a predetermined effective gap equal to or larger than ⅕ of the TTL of the Telephoto lens unit, wherein the first group of at least three lens elements comprises, in order from an object plane to an image plane along an optical axis of the Telephoto lens unit, a first lens element having positive optical power and a pair of second and third lens elements having together negative optical power such that the Telephoto lens assembly provides a Telephoto optical effect of the Telephoto lens unit and such that the second and third lens elements are each made of one of the at least two different polymer materials having a different Abbe number for reducing chromatic aberrations of the Telephoto lens, wherein the second group of lens elements includes a fourth lens element and a fifth lens element made of the different polymer materials having different Abbe numbers and is configured to correct a field curvature and to compensate for residual chromatic aberrations of the Telephoto lens assembly dispersed during light passage through the effective gap between the Telephoto lens assembly and the second group of at least two lens elements, and wherein the first, third and fifth lens elements have each an Abbe number greater than 50 and the second and fourth lens elements have each an Abbe number smaller than 30.

2. The mobile electronic device of claim **1**, wherein light receiving outer surfaces of the Wide and Telephoto lens units are located substantially in the same plane, thereby reducing shadowing and light blocking effects therebetween.

3. The mobile electronic device of claim **1**, wherein the Wide and Telephoto camera units are mounted on separate printed circuit boards.

4. The mobile electronic device of claim **3**, wherein the printed circuit boards are located in different spaced-apart substantially parallel planes.

5. The mobile electronic device of claim **1**, wherein the Wide and Telephoto camera units are mounted directly on a single printed circuit board.

6. The mobile electronic device of claim **1**, wherein the Wide and Telephoto camera units are spaced from one another a distance d of about 1 mm.

7. The mobile electronic device of claim **1**, wherein the Telephoto lens unit has a TTL less than 6.5 mm.

8. The mobile electronic device of claim **1**, wherein the lens elements of the second group of lens elements are spaced from one another an effective air gap smaller than 1/50 of the TTL of the Telephoto lens unit.

9. The mobile electronic device of claim **1**, wherein the Telephoto lens unit has a TTL smaller than 5.5 mm, an EFL larger than 5.9 mm, and an optical diameter smaller than 4 mm, enabling to provide an image on an entire area of a ¼" to ⅓" image sensor.

10. The mobile electronic device of claim **1**, wherein the Telephoto lens unit has a TTL smaller than 6.2 mm, an EFL larger than 6.8 mm, and an optical diameter smaller than 5 mm, enabling to provide an image on an entire area of a ¼" to ⅓" image sensor.

11. The mobile electronic device of claim **1**, wherein the Telephoto lens unit TTL/EFL ratio is smaller than 0.9.

12. The mobile electronic device of claim **1**, wherein the Telephoto lens unit TTL is less than 5.5 mm.

13. The mobile electronic device of claim **1**, wherein the Telephoto lens unit EFL is greater than 5.9 mm.

14. The mobile electronic device of claim **1**, wherein the Telephoto lens unit EFL is greater than 6.8 mm.

15. The mobile electronic device of claim **1**, wherein the Telephoto camera unit includes an image sensor and wherein an image captured by the Telephoto camera unit has a field of view that is no larger than 44 degrees.

16. The mobile electronic device of claim **11**, wherein the Telephoto lens unit EFL is greater than 5.9 mm.

17. The mobile electronic device of claim **11**, wherein the Telephoto lens unit EFL is greater than 6.8 mm.

18. The mobile electronic device of claim **1**, wherein the Telephoto lens unit has an F# smaller than 3.2 and a TTL smaller than 6.2 mm.

19. The mobile electronic device of claim **1**, wherein the first lens element of the Telephoto lens unit has a focal length f**1** smaller than TTL/2.

20. The mobile electronic device of claim **1**, wherein the first, second and third lens elements have respective focal lengths f**1**, f**2** and f**3**, and wherein the respective focal lengths satisfy the condition 1.2|f**3**|>|f**2**|>1.5f**1** and wherein the Telephoto lens unit has an F# smaller than 3.2, wherein the Telephoto lens unit TTL is smaller than 6.2 mm.

21. The mobile electronic device of claim **1**, wherein the Telephoto camera unit includes an image sensor with an image sensor size ¼" or ⅓".

22. The mobile electronic device of claim **18**, wherein the first lens element of the Telephoto lens unit has a focal length f**1** smaller than TTL/2.

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